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TRANSACTIONS

OF THE

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VOLUME XVI

Containing the Papers Read at the Meeting Held at Wheeling, W. Va., February 24, 25, 26, and 27, 1914, Together with Supplementary Discussions and Other Matters.

ARTHUR S. WATTS, *Editor*

This Society is not, as an organization, responsible for the statements of facts or opinions expressed in these papers and discussions.

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BRAY, ARCHIE C., CR.E., Helena, Mont.	Assistant Superintendent, General Ceramic Work, Western Clay Manufacturing Company
BRIGGS, LEONARD S., South River, N. J.	National Fireproofing Company
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BROCKBANK, CLARENCE J., Niagara Falls, N. Y.	Metallurgical Engineer, Carborundum Company
BROWER, FRED., CR.E., Hebron, North Dakota	Hebron Fire and Pressed Brick Company
BROWN, EDMUND, Perrysburg, Ohio	General Manager, Edward Ford Plate Glass Company
BROWN, RALPH E., 740 Pearl St., Ottawa, Ill.	Chicago Retort and Fire Brick Company
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CALDWELL, FRANK WALKER, B.S., in M.E., Lookout Mountain, Tenn.	Chemist, Cast Iron Enamel Work, Cahill Iron Works
CALDWELL, JOHN A., Frostburg, Md.	Vice-President and General Manager, Savage Mountain Fire Brick Company
CAMPBELL, A. R., Metuchen, N. J.	Federal Terra Cotta Company
CARDER, FREDERIC R., Corning, N. Y.	Manager and Chemist, Stuben Glass Works
CASE, W. W., JR., Denver, Colo.	President and Manager, Denver Fire Clay Company
CERMAK, FRANK, 116 4th Ave., Schenectady, N. Y.	Foreman, Porcelain Works, General Electric Company

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CHILD, J. L., Findlay, Ohio	Hancock Brick and Tile Company
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CLAFLIN, W. N., Lancaster, O.	Lancaster Leather Board Company
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COWAN, LOU A., Houston, Washington County Pa.	
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GATES, NEIL H., People's Gas Bldg., Chicago, Ill.	Secretary and Treasurer, American Terra Cotta and Ceramic Company
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HARE, ROB'T L., Collinsville, Okla.	Coffeyville Vitrified Brick and Tile Company
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LAWSHE, C. PERRIN, Trenton, N. J.	General Manager, Trent Tile Company

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LOCKE, FREDERICK M., Victor, N. Y.	Manufacturer of Porcelain Insulators
LOCKE, MORTON F., North Leroy, N. Y.	
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MACMICHAEL, R. F., Auburn, Washington	Assistant Manager, Northern Clay Company
MACMICHAEL, PAUL S., Auburn, Washington	President, Northern Clay Company
MCNAUGHTON, MALCOLM, M.E., Jersey City, N. J.	Superintendent, Joseph Dixon Crucible Company
MADDOCK, A. M., JR., Trenton, N. J.	Vice-President, Thomas Maddock's Sons Company
MADDOCK, HENRY E., Trenton, N. J.	With John Maddock Sons Company

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MANDLE, SYDNEY, Wright Bldg., St. Louis, Mo.	Assistant Treasurer, The Mandle Clay Mining Company
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*MEAKIN, ROBERT J., East Liverpool, Ohio	Manager, Hall China Company
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PENFIELD, R. C., Willoughby, Ohio	President and General Manager, American Clay Machinery Company
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POSTE, EMERSON P., B.S., Elyria, Ohio	Chemist, The Enameled Pipe and Engineering Company
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RANDALL, THEODORE A., Indianapolis, Ind.	Editor, *Clayworker*
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ROESSLER, FRANZ, 39 High St.., Perth Amboy, N. J.	
ROGERS, GREGORY L., 2350 Ellsworth St., Oakland, Calif.	California Pottery Company
ROSE, ARTHUR VEAL, 11 E. Thirty-sixth St., New York, N.Y.	General Manager, Haviland and Company
RUSOFF, SAMUEL, 680 Franklin Ave., Columbus, Ohio	Student, Ceramic Engineering, Ohio State University
RYAN, JOHN J., B.S., Perth Amboy, N. J.	Ceramic Engineer, National Fire Proofing Company
SANDERS, JOHN W., Moundsville, W. Va.	Enameler, United States Stamping Company
SANT, JOHN, East Liverpool, Ohio	President, The John Sant and Sons Company
SANT, THOMAS HERBERT, East Liverpool, Ohio	Secretary - Treasurer, The John Sant and Sons Company
SAUNDERS, WILLIAM EDWARD, B.S., E.M., 1401 Arch St., Philadelphia, Pa.	Engineer, United Gas Improvement Company
SCHACHTEL, S. H., CR.E., Coffeyville, Kansas	Ludowici-Celadon Company
SCHURECHT, HARRY GEORGE, 105 Springfield Ave., Champaign, Ill.	Student, Ceramic Department, University of Illinios
SCOTT, RICHARD, 92 Prospect St., Trenton, N. J.	Monument Pottery Company
SEAVER, KENNETH, S.B., Pittsburgh, Pa.	Assistant General Sales Manager, Harbison - Walker Refractories Company

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SEBRING, CHARLES L., Sebring, Ohio	General Manager, Sebring Pottery Company
SHARKEY, SAMUEL MILLER, 564 E. State St., Trenton, N. J.	Student, Ceramic Department, Rutgers College
SILVERMAN, ALEXANDER, PH.B.,A.B., M.S., Pittsburgh, Pa.	Acting Director, Department of Chemistry, University of Pittsburgh
SINCLAIR, HERBERT, Trenton, N. J.	General Manager, Star Porcelain Company
SINGER, L. P., Lincoln, Calif.	Chemist, Gladding, McBean and Company
SMITH, ALBERT E., Trenton, N. J.	Foreman, Electric Porcelain Company
SMITH, AMEDEE M., Portland, Oregon	President, Western Clay Manufacturing Company
SMITH, HARRY W., 314 Smith St., East Liverpool, Ohio	Representative, Roessler and Hasslacher Chemical Company
SMITH, JAMES M., New Castle, Pa.	Treasurer, Shenango Potery Company
SMITH, NORMAN G., Brunswick, Me.	Treasurer and General Manager, Maine Feldspar Company
SMITH, PERRY A., New Brighton, Pa.	Secretary, A. F. Smith Company
SOLON, ALBERT L., Fairfax, Calif.	Arequipa Pottery
SOLON, MARC, Trenton, N. J.	General Manager and Secretary Mercer Pottery Company
SPEIR, HARRY F., Lewiston, Pa.	Superintendent, Pennsylvania Pulverizing Company
SPIKER, JOHN A., Pocatello, Idaho	General Manager, Idaho Pressed Brick Company
SPRINGE, OTTO, Galesburg, Ill.	Purington Paving Brick Company
SPROAT, IRA E., 1505 W. Second St., Dayton, Ohio	Chemist, Dayton Grinding Wheel Company
STAMM, JOHN, 859 Ohio Ave., E. Liverpool, Ohio	Superintendent, The Croxall Chemical and Supply Company
STANGL, MARTIN, Elgin, Ill.	Haeger Brick and Tile Company
STAUDT, AUGUST, Perth Amboy, N. J.	Treasurer and General Manager, Ostegaard Tile Works
STERN, NEWTON W., Richmond, Calif.	Secretary and Treasurer, Pacific Porcelain Ware Company
STEVENS, DOUGLAS F., M.E., Cayuga, Indiana	Superintendent, Acme Brick Company
STOUT, WILBER, Columbus, Ohio	Geological Survey of Ohio
STOWE, CHARLES BROWN, Cleveland, Ohio	President, National Fire Brick Company

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SWALM, PHAON H., Trenton, N. J.	Assistant Superintendent, Trenton Fire Clay and Porcelain Company
TATTON, JOSEPH, 206 Academy St., Trenton, N. J.	Trenton Potteries Company
*TAYLOR, WILLIAM WATTS, Cincinnati, Ohio	President, Rookwood Pottery Company
TEETOR, PAUL, University of Kansas, Lawrence, Kan.	State Geological Survey
TEFFT, CHARLES FORREST, B.S. (in Cer), Ridgeway, Pa.	Ridgeway Brick Company
TEFFT, THOMAS DWIGHT, Alfred, N. Y.	Student, Ceramic Department, New York State School of Clayworking and Ceramics
TEIPER, JOHN EDWARD, 195 Richmond Ave., Buffalo, N. Y.	Superintendent, Jewettville Brick Company
THOMAS, CHAUNCEY RAPELJE, Essex St., Boston, Mass.	P. F. Thomas
THOMAS, DAVID C., Wellsville, Ohio	Ceramic Chemist, U. S. Pottery Company
THOMAS, GEORGE E., St. Louis, Mo.	General Superintendent, Highlands Fire Clay Company
THOMAS, GEORGE W., East Liverpool, Ohio	President and General Manager, The R. Thomas and Sons Company
THRALL, CHARLES U., Tottenville, L. I., N. Y.	Superintendent, Atlantic Terra Cotta Company
TILLOTSON, EDWIN W., JR., B.A., PH.D., Pittsburgh, Pa.	University of Pittsburgh
TIMMERMAN, WALTER F., Kansas City, Kansas	Superintendent, Western Terra Cotta Company
TONE, FRANK J., Niagara Falls, N. Y.	Works Manager, Carborundum Company
TOWNSEND, EVERETT, 344 Bellevue Ave., Trenton, N. J.	General Manager, Robertson Art Tile Company
TRAUTWEIN, J. O., 417 S. Dearborn St., Chicago, Ill.	President, Trautwein Dryer and Engineering Company
TRUMAN, GAIL R., 5801 Manchester Ave., St. Louis, Mo.	Ceramic Chemist, St. Louis Terra Cotta Company
TURNER, A. M., M.E., Sciotoville, Ohio	Superintendent and Treasurer, Scioto Fire Brick Company
VAN SCHOIK, ELMER HOLMES, B.S., (in Cer.), Box 166, Ottawa, Ill.	Chicago Retort and Fire Brick Company
VODREY, WILLIAM E., East Liverpool, Ohio	General Manager, Vodrey Pottery Company
VOLLKOMMER, JOSEF, Empire Bldg., Pittsburgh, Pa.	President and Manager, The Vitro Manufacturing Company

* Died November, 1913.

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VOLZ, WILLIAM J., St. Louis, Mo.	Superintendent, Evens and Howard Fire Brick Company
WAGNER, FRITZ, 1000 Clybourn Ave., Chicago, Ill.	Vice-President and Treasurer, The Northwestern Terra Cotta Company
WAGNER, FRITZ, JR., B.S., 2525 Clybourn Ave., Chicago, Ill.	Assistant Superintendent, Northwesern Terra Cotta Company
WALKER, CHARLES HENRY, 401 Vine St., East Liverpool, Ohio	Assistant Superintendent, Homer Laughlin China Company
WALKER, F. WM., JR., B.S. (in M.E.) Beaver Falls, Pa.	Superintendent, Beaver Falls Art Tile Company
WALLACE, FRANK M., Chicago Heights, Ill.	
WALTON, SAMUEL FORMAN, Station A, Ames, Iowa	Student in Ceramics, Iowa State College
WANKA, F. O., Los Angeles, Calif.	Manager, Stockton Fire and Enamel Brick Company
WARD, J. W., 628 E. Main St., Latrobe, Pa.	Assistant Superintendent, Pittsburgh High Voltage Insulator Company
WEIGEL, CHARLES, Hebron, N. Dak.	President, Hebron Fire and Pressed Brick Company
WELLS, HARRY B., Canton, Ohio	Superinendent, Belden Brick Company
WHEAT, HOWARD I., 987 Sterling Place, Brooklyn, N. Y.	Vice-President, New York and New Jersey Brick Company
WHITAKER, FRED. A., Keasbey, N. J.	Assistant Superintendent, German-American Stoneware Works
WHITFORD, WILLIAM GARRISON, PH.B. (in Cer.), Chicago, Ill.	Instructor in Design and Ceramic Art, University of Chicago
WHITMER, J. D., CR.E., 9 Ball St., Zanesville, Ohio	American Encaustic Tile Company
WHITTAKER, JOHN L., East Boston, Mass.	Superintendent, New England Pottery Company
WILDER, THOMAS MILTON, Ravinia, Ill.	Proprietor, Wildwood Shop
WILL, OTTO W., Perth Amboy, N. J.	Superintendent, Color Department, Roessler and Hasslacher Chemical Company
WILLIAMS, ARTHUR E., Urbana, Ill.	Ceramic Department, University of Illinois
WILLIAMS, IRA A., M.SC., Corvalis, Oregon	Professor Ceramics, Oregon School of Mines, Ceramist, State Bureau Mines and Geology
WILSON, GEORGE P., Steubenville, Ohio	
WILSON, HEWITT, CR.E., Auburn, Washington	Ceramic Chemist, Northern Clay Company

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WORTH, S. HARRY, 706 Franklin Bank Bldg., Philadelphia, Pa.	President, Pennsylvania Feldspar Company
YATES, ALFRED, Shawmut, Elk County, Pa.	General Manager, Shawmut Paving Brick Company
YEARSLEY, HOWARD S., 304 State St., Camden, N. J.	Manager, Electrical Porcelain and Manufacturing Company
YOUNG, GEORGE F., Zanesville, Ohio	Manager, Roseville Pottery Company
YOUNG, RUSSELL TWIGS, Zanesville, Ohio	Foreman, Roseville Pottery Company
YOUNG, SAMUEL ECCLES, C.E., 3451 California Ave., N. S., Pittsburgh, Pa.	Aid, Bureau of Standards
YOWELL, JOHN BENNETT, Falls Creek, Pa.	Ridgeway Brick Company
ZOPFI, ALBERT S., Toledo, Ohio	Secretary and Treasurer, Buckeye Clay Pot Company

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RULES OF THE SOCIETY

[Revised 1911]

I

OBJECTS

The objects of the American Ceramic Society are to promote the arts and sciences connected with ceramics by means of meetings for the reading and discussion of professional papers, the publication of professional literature, and for social intercourse.

II

MEMBERSHIP

The Society shall consist of Honorary Members, Active Members, Associate Members and Contributing Members.

Honorary members must be persons of acknowledged professional eminence, whom the Society wishes to honor in recognition of their achievements in ceramic science or art. Their number shall at no time exceed two percent of the combined active and associate membership.

Active members must be persons competent to fill responsible positions in ceramics. Only Associate Members shall be eligible to election as Active Members, and such election shall occur only in recognition of attainments in the field of ceramics, and interest in the Society, as evidenced by papers or discussions contributed to its meetings.

Associate Members must be persons interested in ceramics or allied arts.

Contributing Members must be persons, firms, or corporations who, being interested in the Society, make such financial contributions for its support as are prescribed in Section 3.

Honorary Members shall be nominated for election by at least five active members, and approved by the Board of Trustees. Their nomination shall be placed before the Society at an annual meeting, and to be elected they must receive the affirmative vote of at least 90 percent of those voting, by letter ballot, at the next succeeding annual meeting.

To be promoted to active membership, Associate Members must be nominated in writing by an Active Member, and must be seconded by not less than two other Active Members, and must be approved by the Board of Trustees. Their nomination shall be accompanied by a statement of their professional qualifications and a list of their

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publications, if any. Their nominations, when approved by the Board of Trustees, shall be placed before the Society at an annual meeting, and to be elected they must receive the affirmative vote of not less than 75 percent of those voting, by letter ballot, at the next succeeding annual meeting.

A candidate for Associate Membership must make application upon a form, prepared by the Board of Trustees, which shall contain a written statement of the age and professional experience of the candidate, and a pledge to conform to the laws, rules and requirements of the Society. Such applications must be endorsed by two Active Members of the Society as sponsors, and must be approved by the Board of Trustees. The Board may act by letter ballot upon such application at any time, after which an approved candidate may be enrolled on the proper list of the Society upon payment of the fees and dues prescribed in Section 3.

Contributing Members shall be nominated by an Active Member, and approved by the Board of Trustees, and may be enrolled on the proper list of the Society at any time upon payment of the dues prescribed in Section 3.

All Honorary Members, Active Members, Associate Members, and Contributing Members shall be equally entitled to the privileges of membership, except that only Active Members shill be entitled to vote and hold office. The roster of each grade of membership shall be printed separately, in at least one publication issued by the Society annually. Any person may be expelled from any grade of the membership of the Society if charges signed by five or more active members are filed against him, and a majority of the Board of Trustees examines into said charges and sustains them. Such person, however, shall first be notified of the charges against him, and be given a reasonable time to appear before the Board of Trustees, or present a written defense, before final action is taken by the Board of Trustees.

III

DUES

Honorary Members shall be exempt from all fees or dues.

The initiation fee of Active Members shall be ten dollars, and if not paid within three months after the date of their election, the latter shall be null and void. The annual dues for Active Members shall be fixed by the Board of Trustees, and shall not exceed ten dollars.

The initiation fee of Associate Members shall be five dollars, and their annual dues shall be fixed by the Board of Trustees, but shall not exceed five dollars. The privileges of Associate Membership after election shall begin upon payment of the initiation fees, and dues for the first year.

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Contributing Members shall pay no initiation fee into the Society. Their annual dues shall be fixed by the Board of Trustees, but shall not exceed twenty-five dollars. The privileges of membership shall begin upon payment of the annual dues.

Any Active Member or Associate Member in arrears for over one year may be suspended from membership by the Board of Trustees, until such arrears are paid, and in event of continued dereliction, may be dropped from the rolls. Active Members in arrears are not eligible to vote. The annual dues of Active and Associate Members are payable within three months succeeding date of annual meeting.

IV

OFFICERS

The affairs of the Society shall be managed by a Board of Trustees, consisting of a President, Vice-President, Secretary, Treasurer and three Trustees, who shall be elected from the Active Members at the annual meeting, and hold office until their successors are elected and installed.

The President, Vice-President, Secretary and Treasurer shall be elected for one year, and the Trustees for three years; and no President, Vice-President, or Trustee shall be eligible for immediate re-election to the same office.

The duties of all officers shall be such as usually pertain to their offices, or may be delegated to them by the Board of Trustees or the Society; and the Board of Trustees may, at its discretion, require bonds to be furnished by the Treasurer.

Vacancies in any office shall be filled by appointment by the Board of Trustees, but the new incumbent shall not thereby be rendered ineligible to re-election at the next annual meeting to the same office. On the failure of any officer to execute his duties within a reasonable time, the Board of Trustees, after duly warning such officer, may declare the office vacant, and appoint a new incumbent.

A majority of the Board of Trustees shall constitute a quorum, but the Board of Trustees shall be permitted to carry on such business as it may desire by letter.

V

ELECTIONS

At the annual meeting, a Nominating Committee of five Active Members, not officers of the Society, shall be appointed, and this committee shall send the names of the nominees to the Secretary at least sixty days before the annual meeting who shall immediately forward the same to the Active Members. Any other five Active

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Members may act as a self-constituted Nominating Committee, and also present the names of any nominees to the Secretary, provided it is done at least thirty days before the annual meeting. The names of all nominees provided their assent has been obtained, shall be placed on the ballot without distinction as to nomination by the regular or self-constituted Nominating Committee, and shall be mailed to every member, not in arrears, at least twenty days before the annual meeting. The ballot shall be enclosed in an inner blank envelope, and the outer envelope shall be endorsed by the voter, and mailed to the Secretary. The blank envelopes shall be opened by three scrutineers appointed by the President, who will report the result of the election at the last session of the annual meeting. A plurality of votes cast shall elect.

VI

MEETINGS

The annual meeting shall take place on the first Monday in February, or as soon thereafter as can be conveniently arranged, at such place as the Board of Trustees may decide, at which time a report shall be made by the Board of Trustees, Treasurer and scrutineers of election, and the accounts of the Treasurer shall be audited by a committee of three, appointed by the President. Ten Active Members shall constitute a quorum at any regular meeting, and a majority shall rule unless otherwise specified.

The order of business at the annual meeting shall be:

1. President's address.
2. Reading of minutes of last meeting.
3. Reports of the Board of Trustees and Treasurer.
4. Appointment of committees.
5. Old business.
6. New business.
7. Reading of papers.
8. Announcement of election of officers, Honorary and Active Members.
9. Installation of officers and new members.
10. Adjournment.

Other meetings may be held at such time and places during the year as the Board of Trustees may decide, but at least twenty days' notice shall be given of any meeting.

The President shall appoint at the annual meeting a committee of five, to be known as the Summer Meeting Committee, whose duty it shall be to arrange for a summer excursion meeting at some suitable point. The expenses of the Summer Meeting Committee in arranging the program of visits and for printing, rooms and facilities for meetings, shall be borne by the Society.

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VII

PUBLICATIONS

The Board of Trustees shall employ, at suitable compensation, an Active Member of the Society as Editor of its publications. The Editor, together with the Secretary and Treasurer, shall constitute a Publication Committee. The Publication Committee shall provide for the publication of an annual volume, entitled "Transactions of the American Ceramic Society." This volume shall contain a list of the officers, a list of members of the Society, classified into grades, a list of the ex-Presidents, the dates and location of meetings, the annual report of the Board of Trustees and Treasurer, the list of prices of the publications of the Society, the rules of the Society, and any other matter pertaining to the business administration of the Society that the Publication Committee may think proper. It shall also contain such of the papers and discussions thereon as the Publication Committee may consider desirable, and each volume shall contain a list of the papers and discussions and an index. The volume shall be six inches wide by nine inches long, and part of the issue shall be bound in paper covers and part in cloth binding. The quality of the paper, the kind of type, the illustrations, and all other mechanical details of the printing and publishing of the books or reprints shall be in the hands of the Publication Committee, subject to the control of the Board of Trustees.

The acts and policies of the Publication Committee shall at all times be subject to the examination and approval of the Board of Trustees, but the Board shall be bound by contracts entered into by the Publication Committee in the name of the Society. The Publication Committee shall have full power and authority to decide what papers and discussions to publish, which discussions shall be germane to the subject matter, and in what order they shall be published, and in what manner and to what extent they shall be illustrated. In event that the Board of Trustees shall undertake the publication of some other matter or book than the Transactions, the Publication Committee shall act in the same capacity for that publication as in the publication of the annual volume of the Transactions.

One copy of the paper-bound edition of the Transactions shall be sent prepaid to each member of the Society not in arrears. Members desiring cloth-bound copies will be furnished them in place of the paper-bound copy at an increased cost for the binding. No member shall be furnished more than one copy of the Transactions free for any single year. Members cannot purchase extra copies of the Transactions at less than the current commercial rates. A member shall be permitted to purchase one complete file of the publications of the Society at less than the current commercial rate, the amount to be fixed by the Publication Committee and called the Member's rate.

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The Secretary shall have the custody of all publications of the Society, shall keep them safely stored and insured, and shall sell these volumes to the public at prices which shall be fixed by the Publication Committee for each new volume as issued. The Publication Committee shall also, from time to time, fix the price of the old volumes remaining unsold, and shall have authority to refuse to sell the old volumes of the Transactions except in sets, at such time as the quantity remaining of any number becomes so small, as in their judgment to warrant such action.

The Editor shall request the author of each article appearing in the Transactions of the Society to fill out and sign, within a definite time limit, a blank form, specifying the number of reprints of said article, if any, which he desires. This form shall contain a table from which can be computed the approximate cost at which any reprints will be furnished. In event that the expense of furnishing the desired number of reprints is large, the Publication Committee may require the author to pay in advance for part or all of the cost involved before the publication of the reprints is begun. On receipt of such signed order within the time limit set, the Editor shall cause to have printed the desired number of copies. If the author makes no reply, or replies after the time limit has expired, then the Society will not be responsible for the publication of any reprints of the article in question, except at the usual market price for the printing of new matter.

No one shall have the right to demand the publication of an article independent of the discussion which accompanied it, and no one having taken part in a discussion upon an article shall be entitled to order reprints of the discussion separately and apart from the article itself.

The Society is not, as a body, responsible for the statements of facts or opinions expressed by individuals in its publications.

VIII

PARLIAMENTARY STANDARD

Roberts "Rules of Order" shall be the parliamentary standard on all points not covered by these rules.

IX

AMENDMENTS

To amend these rules, the amendment must be presented, in writing, at the annual meeting of the Society, and must be printed on the ballot for officers and sent out not less than twenty days in advance of the next annual meeting, and if the said letter ballot shows an affirmative vote of not less than two-thirds of the total vote cast, then the same shall be declared carried.

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PUBLICATIONS

The following is a list of the volumes published by the Society and the prices at which they are for sale to the general public:

Description of volume.			Bound in paper.	Bound in cloth.
Vol. I.	1899,	110 pages	$4.00	$4.75
Vol. II.	1900,	278 pages	4.00	4.75
Vol. III.	1901,	238 pages	4.00	4.75
Vol. IV.	1902,	300 pages	4.00	4.75
Vol. V.	1903,	420 pages	5.00	5.75
Vol. VI.	1904,	278 pages	4.00	4.75
Vol. VII.	1905,	454 pages	4.00	4.75
Vol. VIII.	1906,	411 pages	4.00	4.75
Vol. IX.	1907,	808 pages	5.00	5.75
Vol. X.	1908,	582 pages	5.00	5.75
Vol. XI.	1909,	632 pages	5.50	6.25
Vol. XII.	1910,	882 pages	5.50	6.25
Vol. XIII.	1911,	837 pages	5.50	6.25
Vol. XIV.	1912,	888 pages	5.50	6.25
Vol. XV.	1913,	747 pages	5.50	6.25
Vol. XVI.	1914,	pages	5.50	6.25
Complete Set			$76.00	$88.00

The Board of Trustees established in the beginning a differential between members of the Society and others, in the matter of prices to be paid for copies of the Proceedings. This differential has been changed from time to time as volumes have grown scarcer and sales increased. The present arrangement, which will stand until March 1, 1915, allows a straight discount of 40 percent to members in good standing. Members in arrears are not furnished copies of the volume for the current year, nor allowed the discount for the older publication. Members are also not permitted to purchase more than one full set of the publications at members' rates. The care and sale of the Publications has been transferred to the Publication Committee, which reserves the right to change the discount from time to time on any one volume or on all, as may be necessary.

The number of copies of the earlier volumes is not large, and members are advised to procure full sets as soon as possible. The prices will never be less and will certainly rise as time goes on.

In addition to the above volumes of the Transactions, the Society

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has also published the following books, which will be sold *net* at the prices listed to the public and members alike:

The Collected Writings of Dr. Hermann August Seger, Volume I. Contains (*a*) Treatises of a General Scientific Nature. (*b*) Essays Relating to Brick and Terra Cotta, Earthenware and Stoneware, and Refractory Wares. Pages, 552. Bound in cloth..... $7.50

The Collected Writings of Dr. Hermann August Seger, Volume II. (*b*) Essays on White Ware and Porcelain. (*c*) Travels, Letters and Polemics. (*d*) Uncompleted Works and Extracts from the Archives of the Royal Porcelain Factory. Pages, 605. Bound in cloth..... 7.50

A Bibliography of Clays and the Ceramic Arts, by Dr. John C. Branner, 1906, 451 pages. Bound in cloth. Contains 6027 titles of works on Ceramic subjects..... 2.00

The above publications will be shipped at the consignee's expense, by express, to any address on receipt of the price. All checks or money orders should be made payable to the American Ceramic Society, and not to the Secretary or the Treasurer.

EDWARD ORTON, JR.,
Secretary.

Columbus, Ohio.

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ANNUAL REPORT OF THE BOARD OF TRUSTEES

WHEELING, W. VA., February 24, 1914.

To the Members of the American Ceramic Society:

The Board of Trustees congratulates the Society upon the passage of another year of successful work, and upon assembling for another annual meeting under such favorable auspices.

VOLUME FIFTEEN

The printing of the annual report was seriously delayed by the unfortunate illness of the Editor, Mr. Homer F. Staley, in July and August. Up to the time of his illness, the work was going well and the volume would have appeared by September 1st at the latest. The delay seemed likely to be short, at first, but towards the middle of August arrangements were made to change editors and let a new man relieve Mr. Staley. A fortunate turn for the better came just at this time, and he was soon able to go on with his work.

The character of the volume speaks for itself. No loss in quality resulted from the break in continuity in the progress of the work, and we think the volume measures fully up to those that have preceded it. The mechanical features of the printing, the paper, typing, and general make-up of the book, we think is an improvement over any of the volumes up to date.

MEMBERSHIP

The membership has stood more nearly stationary than in any preceding year. There has been a healthy growth so far as actual new members initiated is concerned, but the losses have too nearly offset these new members. The statistics follow:

BROUGHT FORWARD FEBRUARY 25TH, 1913:		
Honorary members	2	
Contributing members	5	
Active members, resident	58	
Active members, foreign	7	
Associate members, resident	352	
Associate members, foreign	32	456
ACCESSIONS BY ELECTION DURING THE FISCAL YEAR:		
Honorary members, foreign	2	
Active members,		
Resident	7	
Foreign	3	
Active members restored to the list	1	
Associate members,		
Resident	47	
Foreign	6	
Contributing members	1	67

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LOSSES DURING THE FISCAL YEAR:		
By death,		
Active members	2	
Associate members	4	
By resignation, or by being dropped for non-payment of dues,		
Active members	6	
Associate members, resident	36	
Contributing members	2	50
By promotion from associate to active	7	7
STATUS FEBRUARY 24TH, 1914:		
Honorary members	4	
Contributing members	4	
Active members,		
Resident	57	
Foreign	10	
Associate members,		
Resident	350	
Foreign	41	466
Increase for the year		10
Percentage increase		2.2

The causes which have led to the loss of so many members, both active and associate, are worthy of more careful study. That there will always be some persons who join the Society without any definite ideas or knowledge as to its real nature is to be expected, and such membership is always easily discouraged and drops out as easily as it came in. But it is a matter of serious concern to us all to interest new comers, and to try to imbue them with the enthusiasm which the inner life of the Society always evokes from those who attain it. A step in this direction has been taken for the coming year in getting up a membership card, which not only operates as a receipt for the annual dues, but also makes an efficient card of introduction among members. If the members of the Society will use this card, and will endeavor to accompany its use with the liberal, broad-spirited, and open-hearted courtesy which the earlier years of the Society's existence so fully exemplified, it would seem certain that the influence of this card system will be good and will make itself felt in reducing the number of resignations from lack of acquaintance among members and lack of knowledge or interest in the work of the organization.

FINANCES

The year has been the most successful yet and shows a handsome balance to the credit of the ensuing year.

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Income

Brought forward from 1912-13		$ 249.86
Receipts from dues:		
63 Active members for 1913 @ $7.50	$ 472.50	
344 Associate members for 1913 @ $5.00	1,720.00	
3 Contributing members for 1913 @ $25.00	75.00	
Various fractional payments for 1913 (mostly balances due from previous payments)	32.49	
Collection of dues in arrears	52.50	
Collection of dues in advance (1914)		
Active members	9.00	
Associate members	54.16	2,415.65
Receipts from initiation fees:		
5 Active members @ $10 (1913)	50.00	
45 Associate members @ $5 (1913)	225.00	
6 Associate members prepaid (1914)	30.00	305.00
Receipts from sale of publications:		
Volumes of the Transactions	1,173.37	
Volumes of Branner Bibliography (7)	13.32	
Volumes of Seger's Collected Writings (11)	82.50	
Extras for cloth bindings	142.32	1,411.51
Receipts from sale of reprints	44.90	
Receipts miscellaneous	4.03	48.93
		$4,430.95

Disbursements

Publication of Volume XV:		
Stenographic report	$ 123.20	
Drawings, illustrations and engravings	479.51	
Printing, binding and casing	1,455.78	
Editing	600.00	$2,658.49
Paid for Seger's Collected Writings	79.01	
Author's reprints	82.49	161.50
Paid for Administration:		
Salary of Assistant Secretary	300.00	
Postage, stationery and supplies	208.79	
Insurance	10.00	
Telegraph and telephone	6.60	
Transportation of Transactions (express, freight and mail)	175.07	
Binding and casing early volumes for sale	48.25	
Convention expense	102.46	851.17
		$3,671.16
Balance in bank		759.79
		$4,430.95

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Assets

Cash in bank		$759.79
Accounts Payable:		
Dues and fees, due but not collected	$ 224.91	
Publications sold, but not paid for	148.31	
Reprints sold, but not paid for	57.64	
Books on hand:		
1801 Volumes of Transactions @ $3.70 each	6,663.70	
Inventory of stock, stationery, fixtures, etc., est.	100.00	
Total assets		$7,954.35

Liabilities

None, other than ordinary current accounts, amounting to less than $100 in total.

It will be seen, therefore, that the financial situation is entirely satisfactory, and if it continues thus for another year, will permit some further expansion in our work.

PUBLICATIONS

The following table gives the data as to sales of publications during the year and the status of our stock of books:

NUMBER OF THE VOLUME	NUMBER REMAINING ON HAND FEBRUARY 1913	RECEIVED SINCE	DISPOSED OF BY SALE	DISPOSED OF OTHERWISE	IN STOCK FEBRUARY 1914, BY BOOK COUNT
I	167		11		156
II	137		20		117
III	165		12		153
IV	139		12		127
V	107		13		94
VI	136		13		123
VII	136		12		124
VIII	130		12		118
IX	92		13		79
X	121		13		108
XI	142		14		128
XII	124		18		106
XIII	223		18		105
XIV	133		53	1*	79
XV	...	698	490	24†	184
Branner Bibliography	802		9	17**	776
Total stock on hand					2577

* To the printer, for copy of style.
† To our exchange list.
** Given as bonus for sales of sets.

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The value of the books owned by the Society, at $3.70 per volume for the Transactions, is $6,663.70. There is no reason to doubt that this sum will be realized, in time, and may be largely exceeded. The plan of paying for the Transactions complete each year by the sale of a part of the issue, has permitted the Society to accumulate quite a little property, which is certain to increase in value as the years pass. The low stock of volumes 9 and 14 is significant, and members who have not full sets are again reminded that they ought to be procured before the price is greatly increased.

SUMMER MEETING

The meeting held at New York, Hartford, Worcester and Boston, was a very enjoyable affair and was participated in, in part or in whole by about 35 persons. There was less technical study of plants and more general sight-seeing than in preceding meetings, and more than would be regularly profitable, probably. It was enjoyed nevertheless, in spite of unfavorable weather in the last half of the trip. The value of the Summer meeting as a part of the Society's functions has been again exemplified.

CONCLUSION

The Board regrets that the policy of the National Brick Manufacturers' Association has again carried their meeting out of the geographical zone in which the American Ceramic Society finds it profitable to meet. It hopes that a common meeting point and date will be arranged for next year.

Respectfully submitted,

THE BOARD OF TRUSTEES,

By Edward Orton, Jr., *Secretary.*

TREASURER'S REPORT

February 1st, 1914

Receipts

Balance from E. Lovejoy, Treasurer, as per last report.....	$ 249.86
Total Receipts as per bank book.....	3,827.40
	$4,077.26

Expenditures

Vouchers attached	$3,473.36
Bank balance	603.90
	$4,077.26

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IN MEMORIAM

HARRY B. FOX

WILLIAM GALLOWAY

ROBERT J. MEAKIN

D. V. PURINGTON

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F. T. HAVARD

The Ceramic Society has lost one of its members in the death of Professor Havard, Associate Professor of Metallurgy, in the University of Wisconsin.

He was taken ill with pneumonia in April and had apparently conquered the disease when general toxemia intervened, against which he was unable to rally, and the end came on May 22nd, 1913, at the Madison General Hospital.

Mr. Havard was born at Ipswich, Australia, October 19, 1878. After his grammar school training he entered Sydney University with advanced standing, and in 1897 went to the Freiberg Royal School of Mines, graduating as an Engineer of Metallurgy in December, 1901. Immediately thereafter he came to the United States and entered the employ of the Boston and Montana Company in the capacity of chemist and furnace foreman. In 1903 he accepted the position of manager of the general smeltery of the Anhalt Lead and Silver Mining Company, in which he had a unique experience in successfully handling a wide variety of metallurgical products. In 1906 he accepted the management of the smelting works of the Copiapo Mining Company in Chile, returning to the United States in 1908, when he was engaged in consulting metallurgical work for the U. S. Metals Refining Company and others. He came to the University of Wisconsin in the fall of 1909, and his record of technical, educational and social achievement there is known to a wide circle of friends. His recently published book on "Refractories" is a pioneer in the field and has attracted wide and favorable attention.

In 1908 he married Miss Margaret Raleigh, of Helena, Montana, and he is survived by his wife and one son.

Mr. Havard was a man of rare personality, of cosmopolitan culture and scholarly ability. His genial humor, broad sympathies and high ideals were an inspiration to all who were privileged to know him.

LESTER OGDEN

On January 29th of this year another member of our society was called to his reward. Lester Ogden passed away on that date after a comparatively short illness. With his death went a bright career, as he had made a good foundation for a brilliant future.

After completing the work in the Columbus schools, he entered the Ohio State University in 1906, and graduated four years later, receiving the degree of Ceramic Engineer. During his entire schooling he was considered one of the brightest members of his class.

Since graduation Mr. Ogden has almost continuously been con-

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nected with some phase of the clay working industry, and was successful in whatever he attempted.

We are indebted to him for an investigation of the resistence of porcelain bodies to abrasion which was published in our Transactions.

This society extends its sympathy to his brother and other relatives by whom he was greatly loved.

JAMES PASS

In the death of Mr. James Pass, which occurred on October 30, 1913, at his home in Syracuse, our society has lost one of its charter members.

He was born in Burslem, Staffordshire, England, on June 1, 1856, and came to this country with his parents in 1863. His connection with the industry began in his 13th year when he was apprenticed to a pottery maker at Trenton, N. J. At the age of 18 he removed to Syracuse, and there became a foreman under his father in the Onondaga Pottery. Subsequently he spent three years in the West but returned to the Onondaga factory as general superintendent, and in a short time was given full charge as general manager of the company's rapidly growing business. Under his skillful and energetic guidance he achieved the notable task of changing his factory product from an ordinary earthenware to a superior grade of hotel china, which gave his company an honorable distinction. In addition to this achievement he became associated with Mr. Seymour in the manufacture of electrical porcelain, which undertaking was very successful.

Mr. Pass's appreciation of the value of the application of scientific methods in the ceramic industries was evidenced by his attendance as a student for a year at Syracuse University, where he pursued a special course in Chemistry, and further by his early and continued association with our Society. He was a member also of the Syracuse Section of the American Chemical Society, the Engineers' Club of New York City, and other social and civic organizations. In 1896 and 1897, Mr. Pass had the distinction of being president of the United States Potters' Association.

WILLIAM WATTS TAYLOR

The entire ceramic world has suffered a very heavy loss in the death of Mr. William Watts Taylor. To his never-failing adherence to standards of attainment thought by many to be impossible, is due in large measure the wonderful success of our famous Rookwood

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Pottery, which has done so much to place America in the very front rank as a maker of the best in art pottery.

Mr. Taylor was born in Louisiana in 1847. He attended Harvard University, but due to poor health he was forced to withdraw during his second year. In 1883 Mrs. Bellamy Storer offered him the management of the Rookwood Pottery which she had started three years before. In 1890 the Rookwood Pottery was incorporated and Mr. Taylor was made its president, which position he held until his death on November 12, 1913. In recognition of his signal service in his field of endeavor, Harvard University, shortly before his death, conferred upon him the honorary degree of Master of Arts. In his home city, Cincinnati, he was widely known for his interest in any movement to further developments along the lines of artistic beauty and general welfare.

He combined a charming personality, a wonderful tact and an unfailing loyalty to high ideals of attainment which are but rarely found.

The American Ceramic Society joins with his many friends in all countries in mourning his loss.

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PAPERS AND DISCUSSIONS

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PRESIDENTIAL ADDRESS

CLAY WORKING INDUSTRIES

BY ELLIS LOVEJOY

I sometimes think it is a good plan to take a general view of the industries in which we are interested, and for my presidential address I have chosen a discussion of the status of the common clay industries with which I am familiar.

These industries do not command the attention they should, and few outside the clay workers themselves realize what an important rank they have among the mineral industries of the country.

Coal ranks first with a value of nearly seven hundred million dollars; pig iron second, with four hundred and twenty millions; copper third, with two hundred and five millions; clay products fourth, with one hundred and seventy-two millions. Petroleum is the only other product that exceeds one hundred million dollars in value. Cement the *bete noir* of clays workers with a value of sixty-seven millions comes ninth in the list. The comparison is, perhaps, not fair. In the clay products the valuation is based on the finished product, while in the other mineral products, except coal,—a raw product,—the valuation is on the intermediate product between the raw material and the final product.

However, it is beyond question that the clay industries have a very important rank, and it is also beyond question that they do not command the respect and attention of the financial interests commensurate with their rank.

In antiquity and historical interest, clay working leads all other industries, and we sometimes think this is the greatest stumbling block. It is so old and supposedly so well known that it needs no advertisement.

In the life of man it has a more extended and important use than any other mineral,—shelter, sanitation, road structure, manufacture, farm development, home utensils, ornamentation.

The clay worker is proverbially timid or perhaps conservative is the better word, particularly the brick and tile maker. If

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he would advertise the value of his product and read his own advertisement, he would have more confidence, but instead he reads the advertisements of other products which may replace that of his factory and concludes that it is time to retrench and save what he can from the inevitable wreck. In numerous instances I have been called upon to assure clay workers that slag bricks, sand lime bricks, cement bricks, blocks and tiles, concrete, etc., will not make their investment unprofitable.

In order to get a general view of the trend of the industries, I have drawn the accompanying curves from the data of the government reports. These curves, Figures 1 and 2, cover the reports from 1894 to 1912 inclusive.

First I wish to call attention to the fact that the number of firms has been gradually declining since 1899, while the total output has materially increased. There are nearly three thousand fewer factories in 1912 than in 1899, which means that the smaller plants are being eliminated, and that the business is becoming centralized in larger plants and in combines under one management. It is reasonable to assume that with the aid of the state surveys that there are fewer omissions from the list than formerly, and that a complete list of all the factories would show a greater decline than is shown in the curve. The units in the curve represent one hundred firms, the maximum number of firms being 6926 in 1899, and the minimum 4284 in 1912. The elimination of small plants and concentration in large ones and combination is still going on.

The low mark of production in the industries was in 1897-98, during the McKinley administration, which marks the ebb of the hard times of the previous Cleveland administration, the readjustment of the tariff, and the Spanish war. Under the second McKinley administration, there was an advance in several lines, while others marked time until Roosevelt came into control.

Under the Roosevelt administration there was an encouraging advance in all lines until the end of his regime in 1907, when the senseless money panic caused the most marked slump the industries have ever known. It is to be hoped that the recent currency bill will forever make impossible a repetition of this

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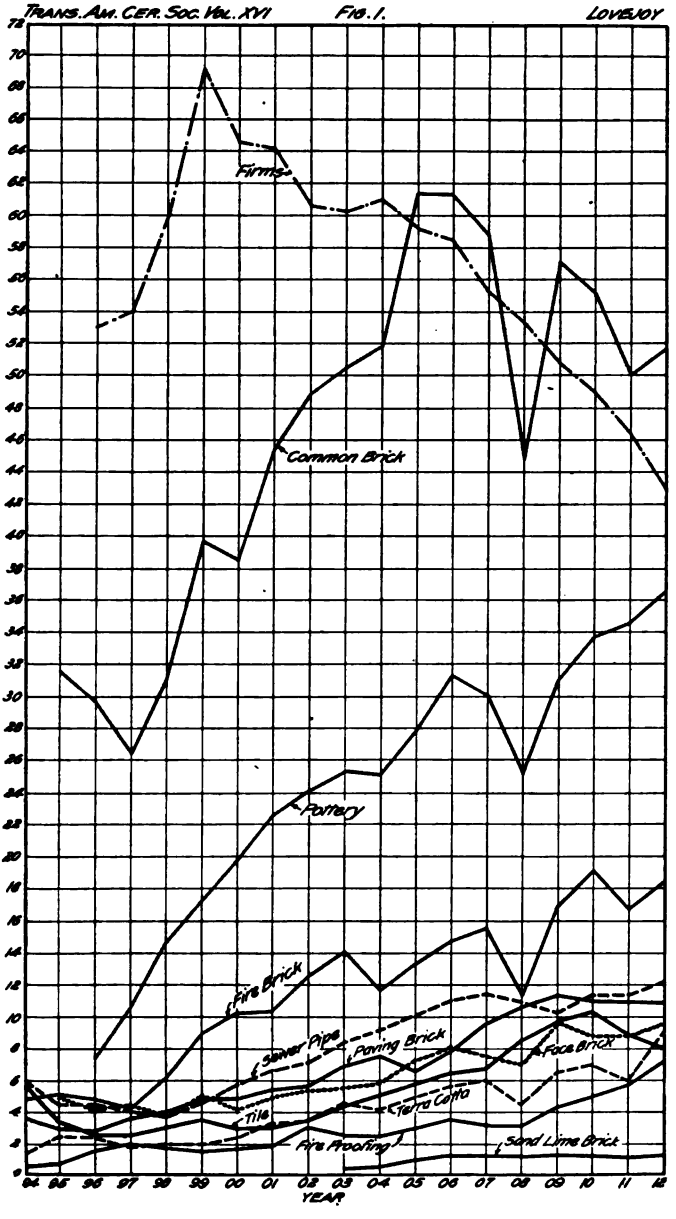

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disastrous and unnecessary panic. Drain tile and paving brick show no drop during this time, while sewer pipe and fire proofing were but slightly affected. Municipal operations, to give the laborer work, account for the level paving brick maintained. Abundant crops which should have made the panic impossible explain the drain tile position. Sewer pipe had contrary influences at work. The pool had been broken up which caused a decline in prices upon which the chart is based, while municipal work helped to maintain the product. Fireproofing was forging ahead at a rapid rate, and the hard times led to a larger use of this cheaper building material at the expense of other materials.

The first years of the Taft administration show the confidence of the country, and we regret to say the effect of the discredited "revision upward" Payne-Aldrich bill is plainly shown in the chart for the year 1911.

In 1904 there was a sag in some of the industries due to strikes and the inability to get sufficient labor to operate the factories.

Fireproofing is evidently a coming product. It has advanced from a very insignificant place to a prominent position. Terra-cotta too, is rapidly coming to the front.

Drain tile is lagging, but chiefly because the business is largely confined to the central west and is over done. The coastal plains of the east coast and of the gulf states, and the great inland basin between the Coast range and the Cascades, are in need of tile, without the factories to supply them. Face brick products have steadily advanced in volume, but the business is not financially in as good a situation as formerly. The profits of the business have diminished almost to the vanishing point. This is due to the fact that the development of the rough texture bricks has let into the market many products which formerly had no place except in the common brick class. The elimination of ornamental brick has also had its effect. Twenty years ago at least 20 percent of the product was in ornamental bricks which commanded a high price, but now the output of ornamentals is less than 2 percent. ($1,128,000 in 1894, $178,000 in 1912).

The demand for face bricks, however, is steadily advancing

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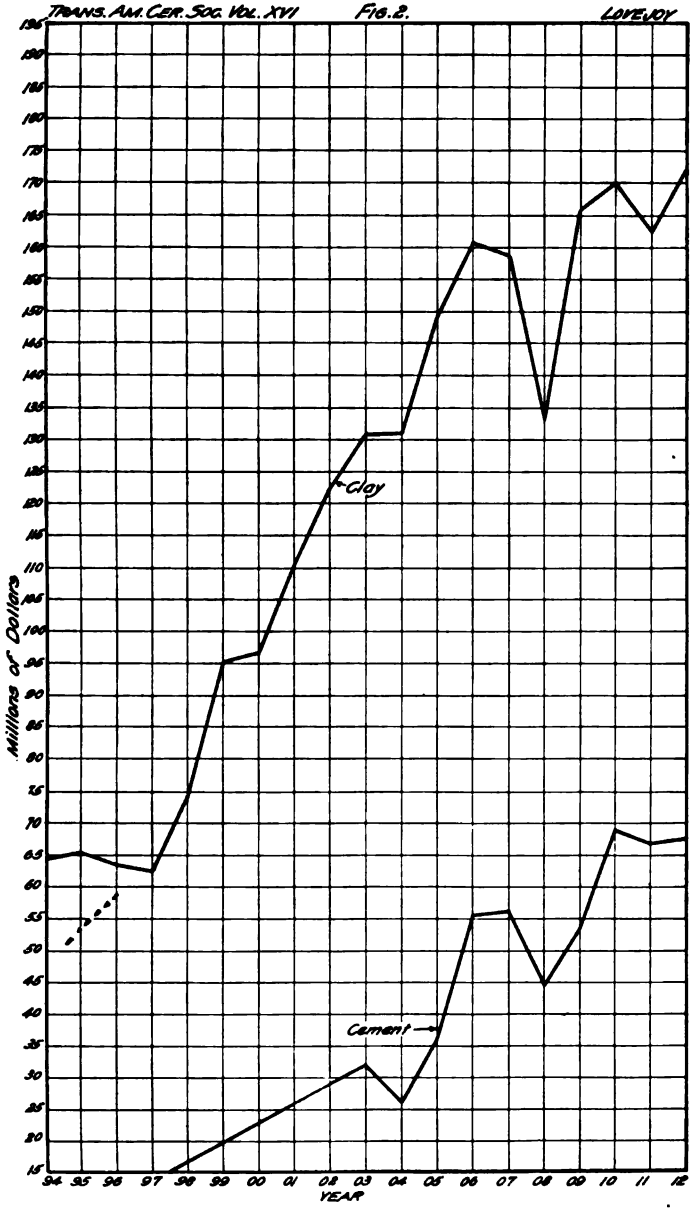

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and soon the market will adjust itself to the output, meanwhile the other products must bear the brunt of new enterprises.

Paving bricks have shared in the steady advance, and the slogan of "good roads" means a promising future for this product. Sewer-pipe shows an inflated curve to 1907, due to the pool, and since then the demand for the product has steadily advanced, but the margin of selling price over cost has materially decreased; and thus the curve has flattened out.

Fire brick is the best gauge in the world of the manufacturing interest of the country. It is evident from the fire brick curve that the clay industries have not fully kept pace with other industries, yet the difference is not sufficient to discourage the clay worker. It is also evident that the clay working industries. except pottery and common bricks, suffered less severely in times of panic than the other industries.

Pottery is more concerned in tariff issues than other clay industries, and within the period of this chart it has enjoyed the benefit of a high protective tariff.

Common brick has had serious ups and downs, but on the whole it has maintained an advance which averages well with the other industries. Concrete has undoubtedly retarded its advance somewhat, and the rapidly advancing fire proofing and hollow block has had some effect, but it is such a large and important industry that these bites out of it have had but little effect on the total.

Now that the Panama canal is practically finished a few timid clay workers have raised again the cement bogie. They need not be alarmed, the six million barrels of cement used in the canal (part of which came from abroad) is less than eight percent of the production in a single year. Cement has nearly reached the minimum cost limit, while clay wares have not, and the demand for better concrete will increase its cost.

The common bricks are the poorest indicator of the state of the clay working industries. Nearly fifteen percent of the entire output of the country is made in the vicinity of New York, and the other money centers use corresponding amounts. These are the first to feel a money depression. because the reserved carried

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in these centers are drawn upon by the outlying districts, and there is a shortage for the local interests.

On the whole there has been a healthy advance in the several lines of the industry, and we are confident of the future. Fire proofing and allied hollow-ware are very promising. Their advance has been natural and will not be checked. They have grappled the concrete bull by the horns, and in the "back to brick" movement we must reckon "brick" as a composite to which fireproofing has given a marked impression.

New ventures in drain tile must seek new fields which are not wanting, nor will the varied crops of this great country be lacking to support the industry.

Paving brick is an assured industry on account of the "good roads" movement.

Face brick must peg along on small profits, until the industry has fully assimilated the influx of rough texture product, and the market has caught up with the supply which it is rapidly doing.

Sewer pipe and conduits are products too necessary to be seriously set back, and the "good roads" movement and the tendency to force public utilities corporations to put wires under ground will help; but it must be admitted the bond market is heavy, and the people are demanding retrenchment in municipal work. However, politicians usually have their way the bonds are placed some how, and the work goes on.

Fire brick will largely be affected by general manufacturing which at present is marking time. The Canadian government has advanced the minimum from $13.00 to $19.50, but this will have little effect,—none on high grade products,—and the export to Canada is but a drop compared with home production.

One reason of the lack of general interest in the clay product is that it receives practically no advertisement. The brick manufacturers are booming a "back to brick" movement, but it is a very weak boom. Outside of the journals devoted to our interests, the advertising is negligible, yet the little that has been done shows the possibilities of persistent effort. Nearly every day, there come into my office pamphlets advertising various building materials—cement, perforated metal and cement, reinforced

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concrete, roofing materials of all kinds,—many of them beautifully illustrated, often containing engineering and architectural data. A number come regularly each month to every architect and builder in the country. Turning to the magazines we find these products similarly presented, and thus the prospective home builders are reached. We do not receive such advertisements of clay products, nor do we find them in the magazines.

A general apathy prevails among the clay workers,—they do not advertise because their product is as old as the hills, and everybody ought to know it is the best building material on earth.

There are six thousand or more clay-working plants in the country (4284 firms reported to the government in 1912, but this does not by any means cover the list), yet not one manager out of twenty attends any of the clay-working conventions, or assists in any way in booming the product. The National Brick Manufacturers Association has an enrollment of about six hundred, of which a notable percentage are not clay-workers, and an appreciable percentage are local members who do not continue their membership in the association.

A recent state convention, we are told, had an enrollment of forty-five, not all of whom were clay-workers, yet there are in that state over 200 operating firms, each of which should have had two or three representatives at the convention. The explanation of the light attendance was that the dues had been advanced to ten dollars for advertising purposes. It is not strange that the men who are trying to put the product in the place it should occupy, get discouraged.

Unfortunately for concerted action and advertising purposes, the clay working interests are not centered in large factories, and the small factories outnumber the large ones ten to one, but as the curve shows, this status is rapidly changing.

The general dilapidated condition of many of our clay-working plants, we think, has considerable effect on the industry. Plants are often on the outskirts of the town, oftentimes alongside the city dump,—the historical tin town,—and comparisons are frequently favorable to the latter. The approach is littered with all the waste of the factory. The factory itself has a general

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appearance of dilapidation,—piles of culls and unsalable product are usually put where they will be most conspicuous. We are not overdrawing the picture,—there are too many such brick yards and tile yards that can never attain the dignity of a factory, enough, certainly, to discredit the industry, and their elimination will be beneficial. It is said that money cannot be influenced by appearance, but, on the contrary, we believe it is the most easily flattered commodity in the world. Any well dressed scheme can command means, and many clayworking factories sadly need new fronts and the prosperity that comes with them.

The clay industry needs a general stirring up, it can no longer maintain its position on the strength of its pedigree; it needs capital badly and will only get it, when it properly and persistently advertises its rank in the mineral industries; it needs a thorough cleaning up, thereby announcing that it is prosperous.

The business is an excellent one in many respects, and when properly undertaken insures comfortable and steady profits. The profits are small, pitifully small in some lines, yet the business has the advantage that, when established on a profitable basis it can continue for many years, and in the end will net a comfortable return.

The costs are largely fixed, because the plant operates on raw material at its door, and the variation in cost comes from changes in wage schedules, in the price of coal, but chiefly in the changes in the capacity of the plant. In times of financial depression the clay industries suffer, but less so than many other industries. (This is not true of the money panic of 1907-08, when banks refused to cash any kind of checks, even their own). The small capital in hard times is inclined to drop its stocks and take up the safer property and building investments. Then, too, the farm is a large consumer of clay products, and it is not affected by business depression. Municipal work is taken up at such times to give labor employment. Thus in a number of ways are the clay industries tided over such hard times.

Bradstreet attributed 86 percent of the failures in 1911 to the following causes:

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Lack of capital	31.4 percent
Incompetence	27.0 percent
Specific conditions	16.9 percent
Fraud	10.6 percent

We doubt if a clay working industry is ever built within the original estimate, and as a result many new enterprises start in under a heavy handicap of borrowed capital, or with an incomplete plant which does not have a profitable capacity.

Under specific conditions the chief item is the difficulty inherent in the clay itself. We feel sure that we are safe in saying that there are more failures in factories built to work a local clay deposit, than in those which draw the raw material from several sources and are independent of local materials. Clay has more trouble in its makeup than all other minerals combined, and in very few instances are these troubles fully determined before the plant is built, with the result that one or more years are required to adapt the equipment to the material, to overcome the difficulties in the clay and to develop a marketable product. This is the period when many factories fail. Costs of manufacture are always underestimated, and many investors are induced to go into the business who would not do so if they had known how small the margin of profit really is. When the numerous troubles develop, when the promised percentages of output dwindle, when the rated capacity is found to be one-half or less, and none of the output up to expectations, then the true cost of manufacture becomes apparent, and the capital is loath to make further investment. It would be a decided advantage to the several branches of the industry if they would publish accurate cost data, and factory results. We believe the time is coming when such data will be made public. Some manufacturers are already advocating such a step, and more will come into line when they see the benefits that will result. The manufacturers will gain in several ways:

1. They will be encouraged to maintain prices.
2. It will deter ill advised adventures.
3. It will put the business on a more permanent basis.

Incompetence is a frequent cause of failure in clay. If we

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were to relate the expensive absurdities that are in operation in nine out of ten yards we visit, it would be said that such operations are inconceivable under the management of competent men, but it is the rule rather than the exception. Clay working factories are working uneconomically in consumption of power, in drying the wares, and particularly in burning. The waste of fuel is enormous, and it is viewed with complacency by the operators.

In mechanical development to eliminate labor, we are not keeping pace with the other industries. We have made some advancement, but the methods of the ancient Egyptians are in use to-day and maintain themselves in competition with the factories that have taken advantage of such mechanical development as has been made. This cannot continue very long in view of the rapidly advancing cost of labor. The factory worker in clay is not receiving the wages that are paid in other industries, and in prosperous times the labor shortage in clay working plants is a serious handicap.

The clay industries are very much behind the times in technical work, but this is slowly being rectified. It was my privilege to enter the clay industry a good many years ago as chemist in a brick yard, and the need of a chemist was considered a joke. There are now many chemists in the business, but compared with the number of factories, the showing is not large. The majority of plants are satisfied to blunder along with the old methods and excessive losses that have been characteristic of the clay industries.

There is an excellent field for the engineer in the clay working industries, excellent for the industries at least, and we hope the time will come when it will be inviting to the engineer. That time has not come, but it is coming. The industry now has some respect for the scientific fellow, but only a few years ago it had little or none. No amount of education could teach a man to shovel coal and clay. The operators knew how to shovel clay and coal, but had not the slightest idea of the inherent intricacies of the one nor the value of the other.

Young men occasionally ask my advice about taking up the

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clay industry as their life's work. It is a difficult question to answer. If a young man wishes hard work, interesting work, and an opportunity to put an industry on a higher plane, he will make no mistake in taking up the manufacture of clay ware. There is nothing spectacular in the work,—no great rivers to span, no mountains to pierce, no monuments to fame, no oceans to connect with water ways, but there is a broad, interesting field in which to work, and from it will come a modest income. It has, I think, greater opportunities than a number of the other mineral industries, and chief among these is the possibility of each one acquiring a considerable financial interest in the business. Clay plants are scattered all over the land, and although small plants are being eliminated, the business can never be concentrated in a few large plants as in other mineral industries, and one may reasonably expect to attain a commanding position. There is always room at the top but the large centralized industries have very few tops, while the clay industries have many. The capital required in the centralized industries is so great that an individual cannot hope to control it, nor sufficient part of it to become a factor in the business.

As a purely engineering field from a financial standpoint, the industry is not promising at the present time. The most encouraging feature is the tendency of the larger plants to employ technical men, and the work now being done by a goodly number of the young men in this Society will open the way for many more, and eventually put the business upon a higher plane and a more economic basis, which will pave the way for profitable general ceramic engineering.

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THE PLASTICITY OF CLAY

BY N. B. DAVIS, ITHACA, N. Y.

INTRODUCTION

In examining a number of very sticky clays from Western Canada, the writer became interested in a study of the cause of this excessive plasticity, and had occasion to review the bulky literature on the subject.

Experiments carried on in the laboratories of Cornell University, under the direction of Dr. H. Ries led the writer to certain conclusions about this important property. Further study is to be made, and this paper is presented as a short review of the literature, and preliminary to a more extensive investigation.

Definition of Plasticity. Briefly, plasticity in clays may be defined as the degree of moldability developed on the addition of water in sufficient amounts. Closely connected with it are those other properties of cohesiveness and shrinkage developed in clays on air drying.

Other substances[1] such as molten metals, glass, wax, etc., are spoken of as being plastic under proper temperature conditions. Plasticity in this sense must not be confounded with plasticity in clays which is developed simply on the addition of water.

Theories of Plasticity. The different theories that have been advanced from time to time to explain the plastic properties of clay may be classified as follows:

A. Structure of the clay particles.
   1. Fineness of grain.
   2. Plate structure.
   3. Interlocking particles.
   4. Sponge structure.

B. Presence of hydrous aluminium silicates.

C. Molecular attraction between particles.

D. Presence of colloidal matter.

Most writers at the present day believe that colloidal matter

[1] Graham, *Lieb. Ann. Cl.*, (1862).

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is the cause of plasticity, but many of these investigators seem to hold different conceptions of just what is meant by the colloidal state.

In the following pages the writer will attempt to review the various explanations that have been given to explain plasticity, and which have gradually led up to the colloidal theory.

A. STRUCTURE OF THE CLAY PARTICLES

In 1867, Johnston[2] and Blake, working on kaolinite, tried to explain plasticity as due to the fineness of grain and plate structure of the kaolinite and other platy minerals present in clays. Clays in which they found kaolinite crystal bundles seemed to be of lower plasticity than those in which the bundles were broken up into cleavage plates. They give analyses of two kaolins of about the same chemical composition, yet one is "fat," and the other is "short." From this they infer that the difference in degree of plasticity is due to the difference in the state of division.

This same view has since been advanced by Biedermann and Hersfeld[3], and Cook[4] in 1878, and more recently by Haworth[5], Wheeler[6], Atterberg[7] and Le Chatelier[8].

Wheeler experimented with fine grinding of minerals, developing a plate structure, and reported that calcite and gypsum, finely ground in a ball mill with water, showed plasticity, and that test pieces gave tensile strengths ranging from 100 to 350 pounds per square inch. Talc and pyrophyllite also showed plastic properties when finely ground, but showed little tensile strength. It is altogether probable that the high tensile strength reported in the case of calcite and gypsum was due to the fact, that some of the mineral matter went into solution and crystallized out as a cement, on drying. This did not happen with the other two minerals, which are more resistant to solution.

Stull[9] tried grinding mica in the same way, found a "sur-

[2] Johnston and Blake. *Am. Jr. Sc.*, 1867.
[3] Bischof, *Die Feuerfesten Thone*, p. 23.
[4] Cook, *Geol. Surv., New Jersey*, 1878.
[5] Haworth, *Missouri Geol. Surv.*, Vol. XI, 1896.
[6] Wheeler, *Missouri Geol. Survey*, Vol. XI, 1896.
[7] Atterberg, *Z. Angew. Chem.*, 24, p. 928, 1911.
[8] Le Chatelier, *Van Bernmelen Gedenkbock.*
[9] Stull, *Trans. Amer. Cer. Soc.*, 1902.

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prising increase in plasticity" and concluded that fineness of grain and plate structure was the cause of it.

Grimsley[10] and Grout, grinding quartz, calcite, and mica noted a development of some plasticity in each case.

Atterberg[11] found that precipitated barium sulphate mixed with 14 percent to 22 percent of water was plastic, but showed little tensile strength on drying. He describes minerals that split into scales or plates, such as barite, kaolinite and the micas, as being strongly plastic if ground and elutriated so that the size of the particles does not exceed 0.002 m.m. Materials like quartz, feldspar and gypsum do not cleave so readily into flat plates and hence are not so plastic. He concludes that the plasticity of the European clays is due to the presence of mica meal in those of the north, and to kaolinite in those of the south.

It is evident that the conceptions of plasticity held by the last four investigators do not agree. Wheeler, and Grimsley and Grout describe quartz, calcite, and gypsum as developing plasticity, while Atterberg describes them to the contrary. All agree that the micaceous minerals do develop plasticity.

Rohland[12] mentions the fact that clays ground in a drag mill are more plastic than those ground in a ball mill, because in the former the particles are brought to a smooth flat form, whereas in the ball mills the grinding produces angular or irregular forms.

Leppla[13] attributed plasticity to the small size of the crystal plates, to inflexibility with elasticity, and to the excellent cleavage and softness of the mineral grains. Further, he was of the opinion that the adhesion between water and the crystal particles is stronger than the cohesion of the smallest cleavage pieces. In this he suggested a new treatment of the subject, little attention to which has been paid since.

Aleksiejew and Cermiatschenski[14], studying Russian clays came to the conclusion that plasticity is due to the interlocking of the clay particles, and depended on a proper mixture of very

[10] Grimsley and Grout, *W. Va. Geol. Surv.*, Vol. III, 1905.
[11] Atterberg, *Z. Angew. Chem.*, 24, p. 928, 1911.
[12] Rohland, *Die Tone.*
[13] Leppla, *Baumaterialienkunde*, 9, p. 124, 1904.
[14] Aleksiejew and Cermiatschenski, *Zap. imp. russk. techn. obschtoch.* 1896.

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fine and coarser grains for its best development. This same idea of interlocking grains was suggested by Olchewsky[15] at an earlier date.

Ternier[16] studied a series of French clays, and found numerous hook-like crystal aggregates to which was attributed the binding power. A study of this structure by Wheeler[17] in a number of Missouri clays showed that in all the clays examined, in which the hook-like crystals were found, the plasticity was low. By grinding, to break up these crystals into their component crystal cleavage plates, the plasticity was increased.

Daubee[18] found that long continued grinding of feldspar in water developed some plasticity, and Olchewsky[19] explained this as due to a spongy porous structure of the finest particles caused by the removal of the alkalies in solution.

All these investigators are agreed on the importance of fineness of grain and plate structure in explaining plasticity.

B. PRESENCE OF HYDROUS ALUMINIUM SILICATES

To fineness of grain and plate structure Vogt, Arons,[20] Bischof,[21] Seger[22] and others have added the idea of the presence and influence of hydrated aluminium silicates in clays as a cause of plasticity. They noted that, in general, the temperature at which kaolinite lost its water of constitution was coincident with the disappearance of plasticity. This was on the assumption that kaolinite formed the basis of all clays, an assumption we know to be wrong to-day.

C. MOLECULAR ATTRACTION BETWEEN PARTICLES

Grout[23] was the first to develop this theory to any extent, although it was hinted at by Ladd,[24] Beyer[25] and Leppla[26] before Grout took it up. He describes plasticity as dependent on two

[15] Olchewsky, *Topf. u. Ziegl. Zeit.*, No. 29, 1882.
[16] Ternier, *Compte. Rendus.* CVIII, p. 1071, 1889.
[17] Wheeler, loc. cit.
[18] Daubee, Cushman, *Trans. Amer. Cer. Soc.*, p. 66, 1904.
[19] Olchewsky, *Jahres-berichte uber Neuerungen und Erfahrungen in der Tonwaren und Kalkindustrie*, 1880-81.
[20] Dammer, *Chem. Tech.*, 1.
[21] Bischof, *Die Feuerfesten Thone.*
[22] Seger, *Collected Writings.*
[23] Grout, *W. Va. Geol. Surv.*, Vol. III, 1905.
[24] Ladd, *Ga. Geol. Surv.*, Bull. 6a, 1898.
[25] Beyer and Williams, *Iowa Geol. Surv.*, Vol. XIV, 1904.
[26] Leppla, loc. cit.

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main factors: first, the distance the clay particles can move on each other without losing coherence, and second, the amount of that coherence or resistance to movement. The first factor will vary with, (a) the shape and size of the grains, and (b) the distance through the water film that they will attract each other. The second factor will vary with (a), the friction in the films, and (b), the friction of the grains on each other. In this, Grout has included the idea of the influence of size and shape of grain, the molecular attraction of grain for grain, the influence of viscosity of the water film. the surface tensions of the liquids and solids involved, and the softness or smoothness of the solid particles.

In his summary of the possible causes of plasticity, he writes that fineness of grain, plate structure, and colloids are insufficient. He may be quoted as follows: "A theory is proposed which bases the cause of plasticity on cohesion and adhesion and suggests that the high plasticity of some clays is due to the greater attraction of those grains for water. As it is shown that such an attraction depends on the constitution of the molecule, any change in the chemical constitution affords a reasonable explanation of the fact that clays of definite composition may vary in plasticity."

By calculating the amount of water necessary to cover the grains of a clay by a water film 0.00005 m.m. thick, he found that the result, in a great many cases, was close to the mount of water needed in tempering to a good plastic mass. If more water is added, the water film increases in thickness, and the molecular attraction is lessened.

Purdy[27] tried to show that the calculated amount of water necessary for such a film is not always equal to the water needed for tempering. Grout, himself, pointed out that the thickness of the water film would vary, and his own reasoning makes his water calculation useless. It is well known that some clays have quite a range through which water may be added to make a good plastic mass, while others may be overwatered very suddenly. This last is often noted in silty clays.

All these theories have gradually led up to the last one on

[27] Purdy, *Ill. Geol. Surv.*, Bull. IX, 1908.

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the classification, the presence of colloidal matter, and in reality this embraces all the other theories if properly applied.

D. THE PRESENCE OF COLLOIDAL MATTER

In taking up the colloid theory of plasticity it would, perhaps, be best to lead up to it by giving a short description of the present day conception of colloids.

In the early sixties, Thomas Graham,[28] an English physicist, working on the phenomenon of diffusion of dissolved substances through organic membranes, found that certain substances passed through freely, while others did not do so, or at most, very slowly. In general, he found that substances of pronounced crystal habit passed through, and other amorphous bodies, such as gelatin, gum arabic, etc., apparently in true solution, did not diffuse. This led him to divide matter into two great classes, colloids and crystalloids. Further work along this line showed that substances, formerly considered insoluble, could be obtained in what appeared to be true solutions, yet they would not diffuse like true solutions. He called these apparent solutions, colloidal solutions or sols.

He found that slight additions of electrolytes, acids and bases, which did not react chemically with the substance in colloidal solution, tended to precipitate or coagulate it. These coagulated sols he called gels, because of their jelly-like nature.

Graham worked with colloidal solution of silicic acid, tungstic acid, chromium, aluminium, and ferric hydroxides. He was not the first investigator to prepare these sols, but he was the first to attempt a systematic investigation of their properties.

Since Graham's time, we have come to know that colloidal means a physical condition that may be taken on, to a greater or less degree, by all substances.

In considering the colloidal condition, we have to think of two phases being present, namely, the solvent and the colloidally dissolved substance. Ostwald[29] and Free[30] have classified the possible phases, calling the solvent the dispersive medium, and

[28] Graham, *Phil. Trans.*, pp. 183-224, 1861.
[29] Ostwald, *Kolloidchemie.*
[30] Free, *Jr. Franklin Inst.*, 1910.

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the colloidally dissolved substance, the disperse phase. Either phase may be considered, a solid, liquid or gas.

CLASSIFICATION OF COLLOIDS

DISPERSIVE MEDIUM	DISPERSE PHASE		
	GASEOUS	LIQUID	SOLID
Gaseous	Class 9: G+G—no real example as gases always are completely miscible.	Class 8: G+L—Fog., e. g. at the point of liquifaction of gases, atmospheric fog. etc.	Class 7: G+S—Smoke, cooled ammonium chloride, vapor, etc.
Liquid	Class 6. L+G—Foams.	Class 5: L+L—Emulsions.	Class 4: L+S—Suspensions, gels.
Solid	Class 3: S+G—Gas inclusions in minerals (pumice) or in metals.	Class 2: S+L—Liquid inclusions in minerals: occluded water; water of crystallization.	Class 1: S+S—Inclusions of solid particles in minerals; solid solution.

The most important are the liquid-solid and liquid-liquid systems, represented by suspensions and emulsions.

To show the relation of these systems with true solution, the following diagram may be given, Figure 1.

Any substance, amorphous or crystalline, may take on the colloidal condition, and there is a tendency toward an equilibrium between these three states and true solution.

Certain substances go under proper conditions from the sol to the gel state, and back again. Such colloids are spoken of as reversible. Others that will not do this, but become set gels, are spoken of as irreversible.

A large number of sols of the metals and their oxides, hydroxides, and sulphides, are known and are being used commercially.

Solium chloride is an example of a substance we know commonly in the solid crystalline state and in true solution, yet,

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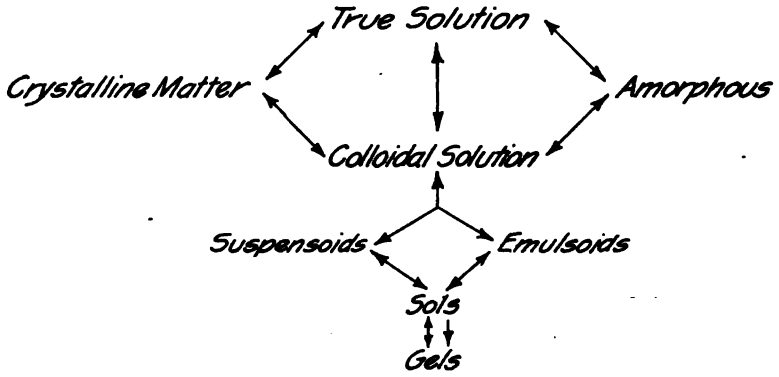
under proper conditions, it has been obtained in the colloidal state.

Besides these artificially prepared colloids, there are a number of substances, such as gelatin, albumin, agar, etc., which can be dissolved as sols without any special precautions. With these sols the solvent need not be water, but will vary in each case. As an evidence of their condition as sols, and not in true solution, it has been found that as sols they have no effect on the boiling or freezing points of the solvent.

TRANS. AM. CER. SOC. VOL. XVI FIG. 1. DAVIS



By the use of the ultra-microscope, invented in 1905 by R. Zsigmondy and H. Siedentopf, we have been able to observe the size of the particles in colloidal solutions. The particles of many sols have been measured and shown to be larger than the calculated size of the molecules in true solution. This difference in size of particles and the inability of colloids to diffuse are the fundamental differences between colloidal and true solution.

The viscosity of colloidal solutions is another important property to be considered. The determination of viscosity is of fundamental importance in investigating the properties of the colloidal state. As Ostwald[31] has pointed out, this constant is extremely sensitive toward small alterations in the condition of the colloid. He considers the variability of viscosity of substances in the colloidal state as due to differences in, (1) concen-

[31] Ostwald, *Trans. Faraday Soc.*, 9, 1913.

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tration, (2) temperature, (3) degree of dispersity, (4) solvate formation, (5) electric charge or ionization, (6) previous thermal treatment, (7) previous mechanical treatment, (8) inoculation with small quantities of more viscous colloids, (9) age, (10) presence of electrolytes or non-electrolytes.

In general, it has been found that the metal and sulphide sols have little effect on the viscosity of the solvent, while organic sols have been found to show marked increase. The organic sols are usually liquid, and this has led us to consider that in colloidal solutions showing an increased viscosity the disperse phase is a liquid.

It has been shown by Stokes in 1850, that a small particle falling in a liquid assumes a constant velocity, and as the radius of the prticle becomes smaller, the rate of falling decreases. Hence with very small particles we may have a suspension that will appear stable for a long time.

Schloesing[32] experimented with the settling of clay suspensions and called the material he found in suspension, after 27 days settling, colloidal.

The writer experimented with the settling of suspensions of three excessively plastic clays from Western Canada. After allowing fifty gram portions to settle in 1000 c.c. measuring tubes for twenty-four hours samples were taken from different depths and examined under the microscope to determine the size of the particles. The curves in Figure 2 show the size of the largest particles, at the different depths. There is much colloidal suspension matter present, as well as emulsion colloids. Number 1 was light colored, and had the least quantity of material in suspension. Number 2 was darker colored, and there was more material in suspension than in Number 1, and Number 3 was the darkest colored and much material was in suspension.

Besides the influence of gravity, there are two other factors to be considered in the stability of a suspension colloid. These are the Brownian movements, and the electric charges on the particles. The Brownian movements are those movements noticed in all fine suspensions, by which, the particles seem to be jumping

[32] Schloesing, *Compte rendus*, 1874.

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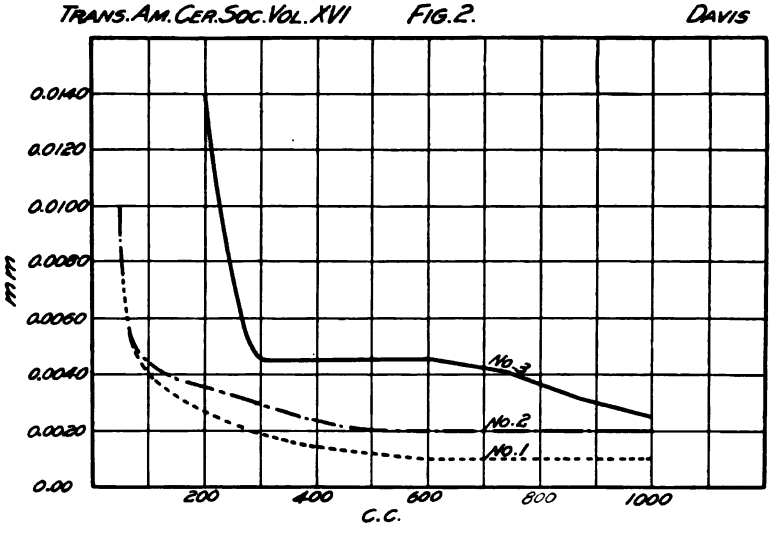
around in all directions in the liquid medium. The Brownian movements are named after their discoverer, Dr. Brown, an English botanist. The phenomenon is explained as due to the impact of the molecules of the liquid on the colloid particles. Clay suspensions show this under the high power of the ordinary microscope. The particles of a suspension are charged alike. and continually repel one another. In true solutions there is electrolytic dissociation into ions, but colloidal solutions have been described by Niklas[33] as couples of molecules retaining a given charge on



the surface like any conductor. Clay particles in water suspension assume negative charges. On the addition of an electrolytic this charge is neutralized, and the particles bunch together and coagulation results.

In 1874, Schloesing[34] experimented with the addition of electrolytes to clays. Since his time many other investigators have experimented with this phenomenon, and most important has been the work of Ashley,[35] in his attempt to control the colloidal matter in clay.

It has been known for some time that the addition of small

[33] Niklas, *Int. Mitt. f. Boden Kunde,* Vol. 3, 1903.
[34] Schloesing, loc. cit.
[35] Ashley, *Trans. Amer. Cer. Soc.,* Vol. XI, 1909; *U. S. Bur. Stand.,* Bull. 23, 1913.

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amounts of colloids, belonging to the emulsion class, greatly increases the stability of a suspension. These colloids that do this are spoken of as protective colloids. They are very much less sensitive to electrolytes than the suspensions. Their effect is explained by assuming that each colloidal suspension particle is surrounded by a thin layer of the emulsion colloid, and then takes the electric charge of the latter.

The most important inorganic emulsion colloid is silicic acid. On the addition of HCl to a sol of this acid it will set to a gel, without the separation of water, and the change is not reversible. It was thought, at first, that this gel represented a definite hydrate, but the work of Ramsay,[36] Spring,[37] von Bemmelen,[38] and others, on dehydration and rehydration, has shown that it is not a definite hydrate, but loses and gains water as the humidity of the surrounding atmosphere varies. Similar work on other hydrates, such as the mineral limonite, has shown that compounds of this nature are not definite hydrates, but take on and lose water with the changing conditions.

Löwenstein[39] experimenting with clays, found that they lost water continuously. Reference may be made here to the recent work of Bleininger,[40] and Brown and Montgomery[41] on the dehydration of clays.

Colloids of the silicic acid type have the important property of adsorption of other colloids and salts from solution, and are known as adsorption colloids. Such hydrous gel bodies are shown to be present in clays by their degree of adsorption. Ashley's method of calculating the colloid matter in clays depends on this property of adsorption.

The organic colloids are very numerous, and many of them are known to be present in clays and soils. In this connection reference may be made to the recent work of the soil research chemists of the U. S. Bureau of Soils,[42], in isolating organic com-

[36] Ramsay, *Jr. Chem. Soc.*, 1877.
[37] Spring, *Zeit. f. Anorg. Chem.*, 1892.
[38] von Bemmelen, *Chem. Centra.*, 1882; *Zeit. f. Anorg. Chem.*, 1900.
[39] Löwenstein, *Chem. Abst.*, p. 887, 1910.
[40] Bleininger, *U. S. Bur. Stand.*, Bull. 1.
[41] Brown and Montgomery, *U. S. Bur. Stand.*, Bull. 21.
[42] *U. S. Bureau of Soils*, Bulls. 53, 74, 75.

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pounds. By the latest published report they have succeeded in identifying some thirty-four different organic compounds.

Clays are simply buried soils, or soils reworked by water, so we may expect to find these organic colloids present to some extent. Whether they are present as emulsion colloids, and acting as protective colloids, has yet to be definitely determined. We do know that many of the excessively plastic sticky clays often contain considerable organic matter.

H. Gedroiz[43] states that such compounds as Fe_2O_3, Al_2O_3, and SiO_2, which result from the decomposition of minerals, are considered hydrosols at the moment of their formation. On the future history of the soil depends the physical and chemical properties. The sols set to gels, and, where organic material is not present as a protective colloid, these soon become solid and amorphous. Where the soil is rich in organic constituents, the latter protect the inorganic colloids from coagulation.

The chief colloidal materials to be considered in clays are silicic acid, aluminium and ferric hydroxides, and the organic emulsion colloids. We may also add the hydroxides of titanium, chromium, manganese, zinc, copper, etc. The alkaline earths are known in the colloidal form, but as such are very unstable, and soon pass to the crystalline state.

All inorganic crystalline substances may be said to be soluble in water to some extent. Of the common rock-forming minerals Buckman[44] gives the following list arranged in the order of solubility from quartz, the least soluble, to nepheline, the most soluble.

1. Quartz.
2. Muscovite.
3. Biotite.
4. Orthoclase.
5. Plagioclase.
6. Epidote.
7. Serpentine.
8. Talc.
9. Hornblende.
10. Augite.
11. Apatite.
12. Olivine.
13. Leucite.
14. Nepheline.

In the light of colloid chemistry, we may consider these minerals, in contact with water, as tending toward a state of equilibrium. At the point of contact there is the tendency of the min-

[43] *Jr. Exp. Landw.*, 9, p. 272-93, 1908.
[44] Buckman, *Trans. Amer. Cer. Soc.*, p. 346, 1911.

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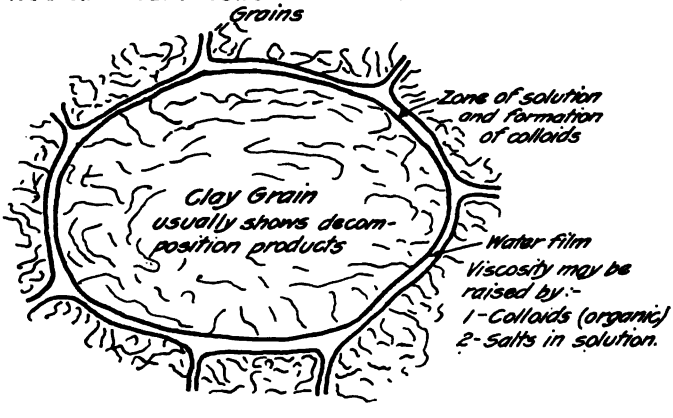
eral to go into solution; but the action is so slow, that the colloid condition has a chance to develop. This equilibrium is well shown in the table given and may be further illustrated by the sketch of clay particles very much enlarged as is shown in Figure 3.

In examining clay grains under the microscope, it is often noted that the crystalline grains all show decomposition products through them and more particularly around their borders. The more soluble constituents are being removed along with infinitesi-

TRANS. AM. CER. SOC. VOL. XVI FIG. 3. DAVIS



mal amounts of the least soluble. At the same time, new mineral combinations are being formed, and part of the oxides produced go into the sol state and may later become gels. Where alumina and silicic acid sols are being formed at the same time, they tend to coagulate one another to gels.[45] Other colloid sols have a similar effect on one another.

The process has been considered essentially one of hydration, as illustrated by Cameron[46] with the mineral orthoclase, as follows:

$$K\,Al\,Si_3O_8 + HOH = KOH + HAlSi_3O_8.$$
$$H\,Al\,Si_3O_8 - SiO_2 = HAlSi_2O_6 \text{—pyrophyllite.}$$
$$H\,Al\,Si_2O_6 - SiO_2 = HAlSiO_4 \text{—kaolinite.}$$
$$H\,Al\,SiO_4 - SiO_2 = HAlO_2 \text{—diaspore.}$$

[45] Stremme, *Centbl. Min.*, 1908.
[46] Cameron, *U. S. Bureau of Soils*, Bull. 30.

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Similar formula might be written to represent the action with other common rock-forming minerals, such as the micas, hornblende, pyroxenes and olivine, except there would be other oxides besides SiO_2, which would tend to the colloidal condition.

In general the rate of decomposition and formation of colloidal material will vary with, (1) the solubility of the substance; (2) the conditions of temperature and pressure; (3) the effect of salts in solution; (4) mechanical treatment; and (5) the effect of organic colloids.

Since Schloesing's time, the colloid theory of plasticity has grown under the investigations of Rohland, Cushman, Atterberg and Ashley. The present-day view of plasticity may be summed up by quoting Ashley as follows: "Almost any mineral, as well as soluble salts, may be present in clays and modify the properties somewhat. The combination of granular and colloidal material is, or should be, in such proportion, that when reduced to proper size, and moistened with an appropriate amount of water, plasticity is developed."

The question to-day is to discover the true nature and quantitative effect of the clay colloids. In the past, methods of investigating clays have been of a qualitative nature.

SUMMARY

After this review of the subject the writer advances the following conclusions:

1. In the decomposition of rock minerals to form clay, the crystalline minerals, under the influence of water and other agencies, tend to form colloidal modifications, soluble salts and more resistant crystalline complexes.

2. The common colloid sols formed are those of silicic acid, aluminium, and iron hydrates.

3. When formed these sols tend to coagulate one another, and form gels.

4. These sols or gels remain, in part, coating the mineral grains.

5. Besides the inorganic colloids, organic sols and gels are present, formed by the decomposition of animal and plant life.

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6. These organic colloids and adsorbed salts tend to raise the viscosity of the waterfilm, hence increasing plasticity.

7. The finer the grain of the clay, the more chance there is for colloidal material to form.

8. The longer the clay particles are subjected to the solvent action of water the more colloidal material is formed.

9. The bonding power and shrinkage depends on the size of grain, mixture of fine and coarse grains and the nature and varieties of colloids of the emulsion class.

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THE FELDSPAR SUPPLY OF THE UNITED STATES[1]

BY ARTHUR S. WATTS

There is no other material used by the potter upon which the success of his business so greatly depends as upon the feldspar. The clays used are, fortunately, from districts having extensive supplies which vary only slightly, and the flint is obtainable in equally uniform quality and great quantity. The feldspar, however, is obtained from igneous intrusions of very irregular structure, and the material mined must be carefully sorted is order to obtain the class of product desired.

The personal judgment of the operator and of his numerous employees regulates the quality of material accepted, and upon the uniformity of this selection the potter depends for his quality of ware. Fortunately, the men employed in sorting the quarried material are trained by long acquaintance with feldspar mining, otherwise serious trouble might easily result. The ordinary practice is to blast a quantity of material loose from the face of the deposit. While fresh holes are being drilled into the deposit for another blast, a crew of men provided with light sledges handle this loose material, knocking off the most impure portions, and by this process, which is known as cobbing, the sorting is effected. The valueless material goes to the dump, while the accepted material goes into a cart or wagon and is generally stacked in heaps in an open place, where the rains are expected to remove any fine dirt or mud adhering to the broken stone. Whether this treatment is of short or long duration, whether it is supplemented by a more effective cleaning, whether the crude feldspar is heaped upon the bare ground, or is protected by a platform, depends upon the judgment of the operator.

A ground feldspar has a color approaching white, and the natural colors in the massive rock will account for any faint creamy tint.

Another cause of variation in feldspar is the irregularity of

[1] Published by permission of the Director, Bureau of Mines.

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the material itself. If feldspar were a single mineral instead of a class of minerals, or if it varied only within narrow limits, the user would be justified in having few fears. If the continuity of a given deposit was such that he could depend upon obtaining his feldspar supply from one source, and could learn the peculiarities of that particular deposit, the problem would be simple. If a deposit suddenly pinches out, or becomes so impure that other material must be added in order to make the product marketable, the chances are that the properties of the material will be somewhat altered, and this will demand a correction in heat treatment. Such a condition must not be charged against the feldspar producer.

The demand is for pure feldspar. Only a small proportion of any deposit consists of pure material, and as this class of material is reduced to the point of exhaustion, while the demand increases, the best portions of the mixed dike material are introduced and are found to furnish a saleable product. As the natural result of such a process of selection, the quality gradually deteriorates, until additions of pure feldspar from newly opened deposits are necessary to produce a marketable product. The question is: How long will we continue to find new deposits of feldspar to supply this demand?

Any person who has given the matter any attention has come to realize that the commercial supply of feldspar, free from quartz is very limited. In France, the supply of feldspar mixed with both quartz and kaolin is very limited indeed, and the famous wares of Limoges are made to-day from the pegmatites of the Saint Yriex district which are partially weathered. These are crushed and pulverized, and to them is added such additional flint and kaolin as is necessary to obtain the desired strength for molding and the demanded translucency when fired.

England has long employed the pegmatites of Cornwall as flux material for her pottery industries, and while the lower grade of Cornwall stone does not produce as fine vitreous ware as the best feldspar, the earthenware of Staffordshire has found a market.

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The feldspars of Scandinavia are also in reality pegmatites, if we may judge from the analyses obtainable.

All of which goes to show that the pure feldspar deposits such as the American potter has been obtaining his supply from, have been exhausted in the ceramic centers of Europe, and the old world potter must content himself with a mixture of feldspar and such other minerals as are not actually injurious when properly prepared. Toward this same condition the American potter is approaching, and the condition is not improved by imagining that we are using the same quality of material as we obtained when the deposits were first opened.

As the necessity for substitution arises, the importance of an acquaintance with the different feldspar producing districts of our country becomes greater.

MAINE FELDSPAR DISTRICT

One of the largest and most important of our feldspar producing districts extends from the Atlantic coast, Sagadahoc Co., Maine, in a northwesterly direction through Androscoggin and the east end of Cumberland County into Oxford County.

The feldspars of this district are, for the most part, pale buff and pale cream colored. Pale salmon feldspar is found only in a few gem bearing pockets. They are chiefly microclines (potash feldspars) with perthitic intergrowths of albite (soda feldspars). Soda feldspar is not common but occurs in limited amounts on Mount Apatite, Androscoggin Co., near Auburn, Me. It is milk white in color and sometimes exists as the lamellar variety, clevelandite. Soda pegmatite also occurs on Mount Apatite as lenses in a potash pegmatite.

The potash feldspar occurring in the pegmatites of Maine is remarkably constant in composition. Analysis from south to north through this Maine district shows the following:

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TABLE I—POTASH FELDSPARS OF MAINE

SiO_2.....	64.67	64.90	65.07	64.97	65.48
Al_2O_3....	19.18	19.75	19.39	19.48	19.39
Fe_2O_3....	0.20	0.12	0.10	0.04	0.08
CaO.....	0.99	.....	trace	.....	.....
MgO....	trace	trace	trace	trace	trace
Na_2O....	2.54	2.68	2.52	2.56	2.85
K_2O.....	12.76	12.04	12.58	11.76	11.51

The soda feldspars of Mount Apatite show the following analyses:

TABLE II—SODA FELDSPARS OF MAINE

	ALBITE	ALBITE PEGMATITE
SiO_2.....	66.36	71.55
Al_2O_3.....	21.35	18.11
Fe_2O_3.....	0.12	0.16
CaO.....	1.10	0.46
MgO.....	0.21	trace
Na_2O.....	9.74	8.72
K_2O.....	0.73	0.64

The potash feldspars have a deformation range of from 1275° to 1295° C. or cone 7+ to cone 8+. They fuse to a transparent glass practically free from tint or shade. The soda feldspars have a deformation range of from 1270° to 1275° C. or cone 7 to cone 7+.

The chief associated impurities of the Maine feldspars are: quartz, due to their occurrence as pegmatites. black tourmaline, which occurs in the southeast portion of the district, muscovite which occurs in limited amounts throughout the district, and biotite which occurs throughout the district wherever the black tourmaline is not abundant. Garnets and beryl are not present in sufficient quantity to affect the quality of the feldspar. The black tourmaline and biotite are eliminated by cobbing. The content of quartz is controlled by the rejection of such material as shows an excessive content of free quartz. The muscovite is removed by cobbing when present in large masses, but when it

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occurs as small flakes, its presence is ignored or its removal is effected by screening the material, after the crusher treatment and before placing it in the ball mill for pulverization.

CONNECTICUT FELDSPAR DISTRICT

This district follows the Connecticut river through Hartford and Middlesex counties for about 20 miles. The feldspars are strikingly similar to the Maine feldspars both as regards composition and physical properties. The color is pale buff and pale cream. The analyses of three average samples taken from the pegmatites of this district is given below:

TABLE III—CONNECTICUT POTASH FELDSPARS

SiO_2	65.64	65.24	66.02
Al_2O_3	19.10	19.74	18.99
Fe_2O_3	0.14	0.12	0.08
CaO	trace	none	none
MgO	trace	none	none
Na_2O	2.32	3.04	3.12
K_2O	12.58	11.84	10.96

These feldspars have a deformation range of from 1270° to 1290° C. or cone 7 to cone 8. They fuse to a transparent glass with practically no trace of color.

Soda feldspar does not occur in commercial quantity in this district but is found as small lenses in most of the deposits, and is also present as a perthitic intergrowth with the potash feldspar.

The associated impurities with the Connecticut feldspar are: quartz, present in the pegmatite, black tourmaline found throughout the district; muscovite found in books in many deposits but also generally distributed as fine flakes in all the pegmatites of this district; biotite scattered through all the dikes, but generally in aggregates of sufficient size to permit of successful cobbing. Garnets occur in negligible quantity.

The chief and only apparent difference between the Maine and Connecticut feldspars is the presence of a slightly higher

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quartz content in the pegmatites of Connecticut than in the pegmatites of Maine.

THE FELDSPARS OF OTHER NEW ENGLAND STATES

Feldspar occurs in New Hampshire near North Groton, Groton Co., as a pegmatite, but this has been worked for mica only, and no data is available as to its value as a source of feldspar.

In Vermont, the existence of vast areas of granite would indicate the likelihood of pegmatite being present, but no work has been done in that state.

In Massachusetts a deposit of feldspar bearing pegmatite occurs near Blandford, Hampden County. This feldspar is similar in every respect to the Maine and Connecticut deposits, but work has been bandoned on account of the haul of four miles to Russell, Mass. which is the nearest railroad station.

THE FELDSPARS OF NEW YORK

The feldspars of this state are of widely varying nature and do not in any respect resemble the New England deposits. For convenience the New York deposits may be divided into the following districts: the Ticonderoga district, the Batchellerville district, and the Westchester County district.

The Ticonderoga District. This district includes the area about Crown Point and Ticonderoga, Essex Co. The feldspar is a mixture of pearl gray potash feldspar and a sea green soda-lime feldspar. The deposits contain large amounts of black mica which is scattered throughout the mass. The soda-lime feldspar carries a high content of iron, and if mixed with the potash variety would render the whole valueless for ceramic purposes. The intimacy of the mixtures of feldspars would render such a separation very difficult, and the major portions of the feldspars of this district are therefore of doubtful value for ceramic purposes, although the potash feldspar is in itself of excellent color. If clean the potash feldspar would make a high grade pottery feldspar, although it fuses at a slightly lower temperature and has a shorter deformation range than most potash feldspars.

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The Batchellerville District. The Batchellerville district includes the areas about Corinth and Batchellerville, Saratoga Co., and Northville, Fulton Co.

The pegmatite of the Corinth deposits contain a feldspar of the pearl-gray potash variety similar to the potash feldspar of the Ticonderoga district. The lime-soda feldspar is absent however, and the biotite present is not so generally distributed. Only a small amount of feldspar has been removed from the deposits at this point. From surface indications, the deposit should produce some valuable pottery feldspar, although the extent of the deposit is not determined, and when opened may prove to be less pure than is indicated in the prospect openings.

TABLE IV

ANALYSES OF FELDSPARS OF THE TICONDEROGA DISTRICT

SiO_2	64.00	65.00	64.01	70.26
Al_2O_3	19.13	20.90	18.28	16.36
Fe_2O_3	0.52	0.10	0.58	0.116
CaO	0.71	0.50	0.74	0.68
MgO	0.28	trace	0.39	0.267
K_2O	12.32	10.45	14.09	8.753
Na_2O	3.06	2.75	1.73	3.116
Ignition	0.32	0.20	0.48	0.43

The Batchellerville deposits are very coarse pegmatites containing large lenses of pure feldspar. Very little mica is present, and such as occurs is chiefly of the white variety. The feldspar is almost exclusively of the potash variety and ranges in color from a pale white to flesh color and pale salmon. None of the green oligoclase found in the Ticonderoga district is noted here. The feldspars of these deposits vary somewhat as regards temperature and rate of fusion, but all are more fusible and have shorter deformation ranges than the Maine and Connecticut feldspars. Their color however is excellent.

The deposits about Northville are pegmatites of varying coarseness. The feldspars present are flesh colored potash feld-

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spar of fine quality and a small amount of soda feldspar of a pale celadon tint. The associated minerals are quartz, biotite and a small amount of muscovite. The soda feldspar fuses to a very pale cream color, and the biotite is generally coarse enough to be readily removed by cobbing, hence these deposits should be producers of some valuable commercial feldspars.

The properties opened in the Batchellerville district have up to the present time been drawn on only for the purest feldspar, and this has been used chiefly to "sweeten" the product of other districts in order to render them marketable. There is much valuable pegmatite unmined in this district, but poor railroad facilities discourage mining at the present time, and none of the properties in this district are now operating.

Westchester County District. The Westchester County district is located just east of Bedford Village and consists of an enormous dike exposed along a ridge and numerous smaller dikes or stringers radiating from the main body. The feldspars of this deposit vary widely. In the eastern portion of the dike, which has a general north-northeast direction, the feldspar is a pink to salmon, potash feldspar, almost free from quartz, and associated with this is a soda pegmatite. Occasional masses of a chalky white soda feldspar are also noted in this portion of the dike. All three forms of feldspar occur in coarse masses, and their separation on a commercial scale is entirely practical. Black mica occurs in some portions of the soda feldspar, but these portions could be easily eliminated. These feldspars are all of excellent color. The potash variety has about the same temperature of, and rate of fusibility as the pure Connecticut feldspar. The soda feldspar is about two cones softer than the potash feldspar and of very short deformation range.

To the west of main deposit and at about an 80 foot lower level, an opening has been made exposing a large deposit of white and dark buff pegmatites. The latter does not resemble the potash feldspar of the upper deposit in appearance, but has about the same deformation range and temperature of fusion.

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TABLE V—ANALYSIS OF COMMERCIAL FELDSPAR OF WESTCHESTER COUNTY, N. Y.

SiO_2	69.45	64.32	73.88
Al_2O_3	16.76	18.68	15.73
Fe_2O_3	0.20	0.45	0.36
CaO	0.45	0.28	0.86
MgO	0.05	0.27	0.36
BaO	0.10	.....	.....
K_2O	9.80	13.24	0.48
Na_2O	2.60	2.73	7.97
Ignition	0.28	0.27	0.40

To the east of the main deposit are several small dikes of cream colored potash feldspar pegmatite, but very little soda feldspar is noted in any of these. The temperature and rate of fusion of these cream feldspars are about the same as those of the pink feldspar of the main deposit.

The feldspars of Westchester County are of good quality but owing to the fact that operators in that district have catered to a cheap class of trade, the feldspar produced has not been of very high grade. With the same care exercised in mining and grinding as is observed in the Maine districts, a product could be produced which for most uses would equal the Maine feldspars.

THE FELDSPARS OF PENNSYLVANIA

The only feldspar producing section of this state is located in Delaware and Chester Counties, along the line of the P. B. & W. R. R. One operation near Pomeroy on the Pennsylvania R. R. is also operated, but the output is worked up into poultry grit.

The feldspars of Pennsylvania are obtained chiefly from pegmatites which have been long recognized as of excellent quality. Most of the large deposits have been exhausted, and at the present time the scrap heaps from some of the original workings are being forked over for the pegmatite which they contain. No single operation in this state is of sufficient extent to supply a mill, and the product of several small quarries are purchased and delivered to a central mill which blends them.

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The feldspars are of both the potash and soda varieties. The colors of the potash feldspars are buff to salmon, the soda feldspars are white with a milky tint. The impurities, aside from quartz, are muscovite (rum and green mica), and in a few quarries, red garnets and biotite (black mica). The last two are generally confined to limited zones, and can be easily detected, so that their complete elimination from the acceptable material is merely a matter of care in sorting the crude feldspar before grinding. The soda feldspar present in the pegmatite dikes of Pennsylvania occurs in two general forms, (a) as fine intergrowths in the potash feldspars and (b) as small irregular masses in which the soda feldspar replaces the potash feldspar almost entirely. In the latter form, the quartz content of the pegmatite is much in excess of that present in the graphic potash pegmatites, and hence this form of feldspar was rejected during the early years of the Pennsylvania feldspar operations. As the pure feldspar masses became exhausted, and the graphic granites and pegmatites came to be used, this soda pegmatite came into use also. Hence the feldspars of Pennsylvania are to-day marketed with not only a higher quartz content, but they also contain a somewhat higher soda content than in the early days of operation in this district.

For comparison there is given below three analyses of potash feldspar from the same mill at intervals of three years:

TABLE VI—PENNSYLVANIA POTASH SPARS

	1904 ANALYSIS	1907 ANALYSIS	1910 ANALYSIS
SiO_2	65.78	68.60	69.05
Al_2O_3	19.12	18.40	17.40
Fe_2O_3	.....	0.54	0.15
CaO	0.41	0.30	0.12
MgO	0.12	0.14	.....
K_2O	11.91	10.52	10.03
Na_2O	1.82	2.00	2.97
Volatile	0.80	0.17	0.42
	99.96	100.67	100.14

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The proportions of soda feldspar present in this last feldspar is not in any sense excessive, and in fact is lower than most Connecticut feldspars at the present time.

The largest deposits of soda feldspar ever found in the United States, and possibly the largest in the world, were located along the boundary between Chester Co., Pa., and Cecil Co., Md. These deposits are classified as soda pegmatites by Bastin (Bull. 420, U. S. G. S.), but not in the sense that they are mixtures of feldspar and quartz. No quartz is crystallized with these deposits of soda feldspar. The chief impurities are dark green hornblende and muscovite. The latter occurs only in small amount; the former is scattered throughout the dike and must be removed on account of its objectionable color. The enormous deposits of the soda feldspar which made this district famous have been almost exhausted, and operations are now confined to a few narrow dikes which are doubtless stringers of the chief deposits.

Thus it appears that Pennsylvania as a feldspar producer has begun to decline, and unless new and extensive deposits of superior quality are found, the potter must look elsewhere for at least a large portion of the material formerly obtained from this field.

THE FELDSPARS OF MARYLAND

The feldspar producing area of this state lies in Howard and Baltimore Counties. The quality of feldspar obtained from Maryland varies widely. In some places, the dikes are so weathered that the material is forked over, and the solid pegmatite separated from the dirt in the same manner as that employed in some places in Pennsylvania for recovering the feldspar from the old dump heaps of the feldspar quarries. In most places, the feldspar is solid and occurs as a coarse pegmatite of two types, viz., potash feldspar of a cream to salmon color, and soda feldspar of a chalky white color. Both are medium grained pegmatites, and rarely occur in graphic form. Biotite, which occurs in small amount in the Pennsylvania deposits, is very common in this district, and its complete removal demands great care if the product is to be of a desirable quality for pottery

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uses. The feldspars are not unlike the Pennsylvania feldspars, and as the soda feldspar pegmatite is more abundant than in Pennsylvania, this district may be expected to provide a soft feldspar to replace in part the shortage of the pure soda feldspar of Pennsylvania.

THE FELDSPARS OF VIRGINIA

While feldspar deposits are reported at numerous points in this state, the actual production has been very small, and all the deposits so far opened have been worked for a short time and for various reasons have been abandoned. This is the case with the quarries at Prospect and Jetersville, and the quarries about Amelia Courthouse. While producing feldspar of excellent quality, these quarries have been operated for mica and no attempt has been made to remove the feldspar. An abandoned mica mine near Hewletts Station, Va. shows some superb albite, but operations here have been long discontinued, and no large amounts of feldspar were ever removed from the shafts.

A pegmatite dike near Lowry Station, Bedford Co. is exposed for a considerable distance. An analysis shows this to be a good mixed feldspar of the composition:

SiO_2	68.75
Al_2O_3	18.56
Fe_2O_3	.03
CaO	1.25
MgO	trace
K_2O	6.85
Na_2O	4.29
Volatile	.10
	99.83

FELDSPARS OF NORTH CAROLINA

The feldspar deposits of this state are distributed throughout the mountain section southeast of the Great Smoky Mountains. The most promising districts are those described in Bulletin 53, U. S. Bureau of Mines, as the Cowee District and the Sprucepine District. The former includes portions of Jackson,

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Macon and Swain Counties and the latter includes portions of Yancey, Mitchell and Avery Counties. The feldspars throughout this state are generally cream white microclines with very low soda content. A few small deposits of soda feldspar and anorthoclase have been observed, but the great majority of deposits in North Carolina are of potash feldspar. This occurs as extremely coarse pegmatites in the majority of cases; and the field being new, a large amount of pure feldspar is to be found as pure lenses in the pegmatite. Many of the pegmatites are so coarsely crystalline that the quartz content can be almost entirely removed by cobbing. The dikes are seldom large, however, and as they stand almost vertical in a majority of cases, the problem of mining is more difficult than where the deposits are large lenses or lie nearly flat, as is the case with many deposits farther north. The chief impurities are quartz and muscovite (white mica), with smaller amounts of biotite, (black mica), beryl and garnets. The latter three, however, are seldom present in quantity to seriously affect the color of the product. while the muscovite is generally coarsely crystalline and not generally distributed throughout the entire mass. The mining in the lower district is confined to operations for mica, and no attempt is made to remove the feldspar except where it interferes with the mining of the mica. In the Sprucepine district, three feldspar quarries are now in operation, and others are to be opened in the near future. The potash feldspars of North Carolina may be safely represented by the following analyses:

TABLE VII—NORTH CAROLINA POTASH FELDSPARS

SiO_2.....	64.48	65.37	63.90	65.68	64.93
Al_2O_3....	19.43	17.92	19.97	19.08	19.45
Fe_2O_3....	0.01	0.02	0.15	0.14	.....
CaO.....	.....	0.17	0.05	.....	0.05
MgO....	.....	.....	.....	.....	.....
BaO.....	.....	.....	0.70	.....	.....
K_2O.....	13.19	13.05	13.20	13.09	12.46
Na_2O....	1.84	2.10	1.01	2.08	2.54
Ignition.	0.90	0.17	0.60	0.30	0.40
	99.85	98.80	99.58	100.37	99.83

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Feldspars have been found in Georgia and are now being investigated by the Georgia Geological Survey, but up to the present time no operation of commercial feldspar quarrying has been attempted in that state.

The foregoing sets forth the general location and extent of the feldspar deposits in the United States east of the Mississippi River. A few words must be said regarding the value of the material in its natural state, and the influence of the method of mining and grinding upon the quality of the finished product. The feldspars of Maine, for example, are not naturally very pure feldspars. In fact, no feldspar producing section in the United States has so many injurious minerals associated by nature with its feldspars. Nevertheless, the Maine feldspars are furnished to the potter in a state of purity second to none, if we except the quartz content, which cannot be eliminated and which must of necessity increase with continued mining operations in any district. This high state of purity is obtained by untiring vigilance on the part of the miner and at the mill to insure against even the smallest introduction of iron bearing impurity.

The first duty of a feldspar mill operator is to remove all associated iron bearing minerals from the crude feldspar, and once clean, to guard against any iron or other coloring material contaminating the feldspar during the milling process. This not only includes the elimination of mica, hornblende, garnets, etc., which may be associated with the feldspar in the dike formation, but also the removal of surface soil which may be adhering to the crude masses of feldspar through the action of drainage waters which have run into the quarry, or which may be attached to the rock through the practice of piling the crude feldspar upon the bare ground pending its removal to the mill.

The general opinion prevails that the small amounts of impurity which cause a natural feldspar to be cream, buff, brown or salmon, are lost in the fusing process, and that a dark feldspar may fuse to as perfect a white glass, as is the fused product of a pure white feldspar. This is not true so far as the investigations connected with this study have indicated. The intensity

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of color in the fresh feldspar is, however, no indicator of the intensity of color in the fused feldspar, nor of its coloring action in the pottery body or glaze.

In general, the feldspars which fuse to the most colorless or white glasses are those which are pure white or colorless. The next in order are the pale salmon and nearly transparent feldspars. The next are the cream feldspars. These are generally opaque, or nearly so. The next are the brown and buff feldspars. The last and most highly colored when fused are the sea-green or olive green feldspars.

This classification is for feldspars which do not contain any foreign material, other than that distributed uniformly, as a colorant, through the entire mass.

The range of tints obtainable within the variation of natural feldspars, with the exception of the olive or sea-green feldspars, are only posible of detection where the materials are prepared with the utmost care. Any dirt or dust on the surfaces of the crude feldspar, or carelessness in the crushing or grinding process, may result in a fused product of a color far inferior to any obtainable by fusing the darkest colored natural feldspar, the olive green or sea green feldspars excepted.

The problem, then, resolves itself into one, not entirely of obtaining the feldspar of the best natural color, but more especially of guarding against the introduction of impurity naturally associated with the feldspar, and also of impurity which may be introduced in the milling process.

DISCUSSION

Mr. J. B. Shaw: I should like to ask Mr. Watts the relative soda and potash composition of the highest soda feldspar obtainable.

Mr. Watts: There is a soda feldspar in Pennsylvania near the Maryland line, which runs about ten percent soda, or nine and a half percent soda, and one percent potash, but it also contains a considerable amount of magnesia and lime. This deposit I understand is now controlled and used exclusively by one concern. Therefore, the soda pegmatites are practically the only

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sources of soda feldspar available, and these would run perhaps, six percent soda and four percent potash, or about those figures.

Mr. Denmead: I want to ask Mr. Watts what he would expect from a feldspar containing less than 5.4 equivalents in SiO_2.

Mr. Watts: I should say that it was not a feldspar.

Mr. Denmead: It has the feldspar structure, and certainly seems like it microscopically and every other way.

Mr. Watts: I should be much interested in seeing it, as there is no record of its existence made by any of the geologists.

Mr. Denmead: A sample of it was sent me the other day, together with its analysis.

Mr. Watts: Of course you might have a leucite, which is a potash silicate the same as feldspars are, but it could not properly be classes as a feldspar.

Mr. Denmead: I have not gone into the matter deeply, but I examined the sample under the microscope, and it certainly appeared to be a feldspar. I was greatly surprised at the analysis of it, and that is why I asked the question.

Mr. Watts: I never saw a feldspar of that kind, so I could not say anything about it.

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NOTE ON THE RESTORATION OF PLASTICITY TO POTTERY SCRAP CLAY

BY J. MINNEMANN

In the pottery industries where the loss in drying is considerable, the question of disposing of unfired scrap clay becomes a problem. Ordinarily this scrap is used up daily as made and as long as the proportions remain within certain limits, no trouble is experienced. Occasionally, however, due to delay in shipments, break downs, etc., this material accumulates and must be disposed of quickly.

The clay after having been made up into ware and dried is found to be less plastic when reblunged and repressed. This is evidenced in the shorter time necessary for filter pressing, by the action in the pug mills as described by Simcoe[1], and in the increased losses in the green state.

It has been suggested that in drying, certain colloids become set, as in the case of the preheating of Illinois joint clays described by Bleininger[2]. In no case, however, was such a change noticed at so low a preheating temperature as prevails in a steam heated pottery dryer. Further, upon drying the clays used in the body, before blunging, no change in the working properties is noticed, and this would lead one to believe that the drying of the scrap clay had little to do with the loss of plasticity.

The loss in plasticity might be attributed to the washing out of soluble salts in filter pressing. Where the water from the presses is not reused in its entirety, this theory seems quite probable, in view of the fact that the water from the presses contains considerable soluble material.

Whatever the cause of this change may be, the writer has found that the plasticity may be restored by the addition of such electrolytes as tend to coagulate clay slips. Hydrochloric acid, magnesium sulphate, calcium sulphate and vinegar were used

[1] *Trans. Amer. Cer. Soc.*, Vol. XI.
[2] *Trans. Amer. Cer. Soc.*, Vol. XI, p.358.

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on a commercial scale, in amounts varying from 0.05 to 0.1 percent, with scrap clay made from both English and domestic clays, the soluble salts being added to the scrap clay in the blunger.

When used in proper amounts all showed nearly the same result, a restoration of plasticity equal to the original. Magnesium sulphate in amounts of 0.07 percent was found to be the most satisfactory, everything considered, and has been used commercially for several years, as occasion demanded.

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NOTE ON THE TRANSVERSE TEST APPLIED TO POTTERY PLASTER

BY F. B. ALLEN, CER.E., WASHINGTON, D. C.

The data in the following experiments were obtained in connection with a test performed upon a carload of defective plaster, while the writer was in the employ of the Pittsburgh High Voltage Insulator Co., of Derry, Pa.

This plaster had the following marked properties: Sometimes it would set very rapidly, sometimes slowly with a settling to the bottom of the stirring can. Its color was a very pale or light pink. The molds made from it gave variable results; some would break almost as soon as they were put in the machine, others would last longer. We had about seventy-five barrels of this material on hand which could not be used directly.

The material was sampled and analyzed, giving the following results:

$CaSO_4$	88.20	
H_2O	6.70	(Combined and free)
	94.90	

A precipitate of $Al(OH)_3$ was formed when the solution was neutralized with NH_4OH. This was filtered off but not weighed. The theoretical composition of pottery plaster is $(CaSO_4)_2H_2O$, which gives on a percentage basis:

$CaSO_4$	93.8
H_2O	6.2
	100.0

Comparing these figures with the above, $CaSO_4$ is seen to be low, and moreover the precipitate of aluminium hydroxide argues the presence of some foreign material, probably clay.

Grimsley in "*The Gypsum of Michigan,*" says that the tensile strength of good plaster is about six hundred pounds per square inch. This was the initial strength of briquetts, some of

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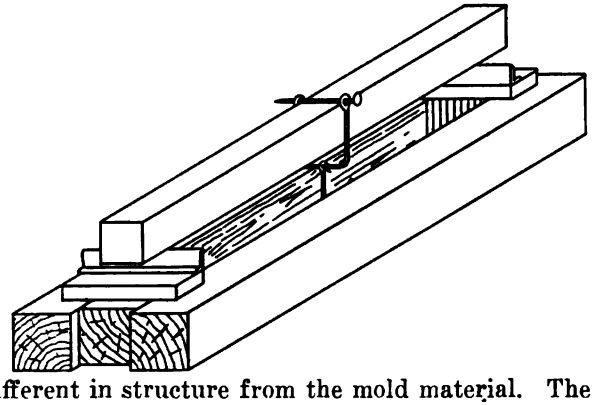
which were subjected to various conditions of temperature and moisture and the effects upon the tensile strength noted. The initial strength was around 600 pounds. Since a tensile strength machine was not available it was decided to try the transverse test, of which the data below are the result. Five bars, eleven inches long by three-quarters of an inch square in section, were made from good plaster. Five similar ones were made from the defective plaster. They were made by the mold maker in the usual manner, no particular care being taken to make the sam-

TRANS. AM. CER. SOC. VOL. XVI FIG. 1 ALLEN



ples different in structure from the mold material. The samples were dried three days on steam. The test was then performed on the bars as shown in Figure 1. The bars were suspended on knife edges and broken by means of a load applied at the middle. This load consisted of a bucket into which water was poured until rupture occurred. The extreme stress was then calculated from the usual formula:

$$S = \frac{3}{2} \cdot \frac{Pl}{b\,d^2}$$

where S is the modulus of rupture in pounds per square inch.
P is the suspended load.
l is the span in inches.
b is the width of the section.
d is the depth of the section.

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The first five are the good plaster samples, the last five are those of the defective material. The span was originally intended to be ten inches, but the limits of the knife edges, as constructed, were only nine inches.

TABLE I—TRANSVERSE TEST OF PLASTER

SAMPLE	P *pounds*	l *inches*	B *inches*	D *inches*	D^2 *inches*	S
1	27.31	9	0.81	0.87	0.757	600
2	21.84	9	0.72	0.80	0.640	640
3	29.47	9	0.78	0.94	0.884	575
4	19.47	9	0.75	0.78	0.608	567
5	30.37	9	0.81	0.87	0.757	660
6	26.31	9	0.72	0.69	0.476	1035
7	19.00	9	0.78	0.81	0.656	500
8	25.03	9	0.69	0.69	0.476	1030
9	26.81	9	0.78	0.81	0.656	700
10	27.81	9	0.75	0.75	0.563	890

What we want to call attention to, is the average of the first five tests, 608 pounds. The results for the different beams of this group are remarkably close together and of the same magnitude as that indicated by Grimsley as the tensile strength of good plaster. The results of the defective material vary too much to give an average. The results were similar to the behavior of the molds, some poor, others too good to be true.

Conclusion. The writer does not believe that the transverse formula holds rigidly for such materials as plaster, that is, that it stands the same load in compression as in tension, or closely follows Hooke's Law. Nevertheless the results upon the first five beams are of the proper magnitude, and the method herein used of comparing the good with the defective plaster, gives a test of which every potter can take advantage.

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THE NEEDS OF THE GLASS MANUFACTURER IN THE WAY OF REFRACTORIES

BY C. W. BERRY

Very little has been published upon the subject of glass house refractories, such as flux blocks for tanks and mixes for plate and lead glass pots. This is due perhaps to the secrecy observed by the manufacturers of these products. Each manufacturer has his mixtures of clays and processes of manufacture, which are jealously guarded. Some of these mixtures have been handed down from one generation to another, with very few changes if any. Some mixes are merely a matter of guess work, and a tank block or pot mix is placed on the market before being tested. A year usually passes before the value of such a mix can be determined, as considerable time is required for manufacture. In case the service secured from the product is unsatisfactory, further changes are made in the mix, and another long period must elapse. This is continued year after year, until a satisfactory mix is found. Such a method of testing is at the expense of the glass manufacturer.

Considerable work has been done in the Research Department of Laclede-Christy Clay Products Company, since the department was established about fifteen years ago, in testing clays, and developing and improving mixes. A representative visited Europe and studied the methods of testing clays and the manufacture of pots and tank blocks. Most of the early work was devoted to improvements in manufacture and treatment of clays.

In 1908 the work of testing mixes with glass batches was started. The first experiments along this line were of selecting clays appearing to have value for glass house refractories and making up blocks and pots of small size, the pots being 4 in. by 4 in. with ¾ inch walls, and the blocks 2 in. by 2 in. by 4 in. Each pot or block was made of a single clay, using 50 percent raw and 50 percent burnt. The blocks were tested in a small tank with glass batch, and the pots were tested by melting glass batches in them.

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These tests were on rather a small scale, but they were of importance in determining the value of clays for the purpose. The next step was to make mixtures of the best clays and test them in the same manner.

About two years ago, it was decided to conduct the experiments on a larger scale, and to follow as closely as possible, the methods used in the glass factories.

Over one thousand clays have been tested since 1908. Sixty-nine glass melting tests have been conducted and ninety-three different mixes tested during the same period.

The Christy plastic fire clay has been used for tank blocks and pot mixes for many years, and is used in both the crude and washed forms. The Christy Fire Clay Co. began washing clay in 1857, and since that time this clay has been used by nearly every glass and pot maker in this country. The clay is found within the city limits of St. Louis and extends into St. Louis County. The center of the area is a section of the city known as Cheltenham, south of Forest Park. The clay is secured much after the manner of coal mining, both shafts and slopes being used. The depth below surface is about 75 feet, and the thickness of the seam averages 7 feet. There are some variations in the clay in different sections, especially in the amount of silica and impurities. The best grade of pot clay occurs in the Oak Hill district about one mile south of the Cheltenham district.

Only the best of the clay is used for tank blocks and pot mixes, a careful selection being made in the mine and on the surface. Part of the clay is pure enough to be used in the crude condition, while another grade is weathered and washed and put on the market in raw and burnt blocks or ground to various degrees of fineness. The clay left after the selecting and picking, is used in other products not requiring the highest grade clays.

This St. Louis clay makes a good tank block or pot when used alone, but it is the usual practice to add other clays higher in plasticity and maturing at lower temperatures in order to form a body that is stronger and more dense, and which resists the action of fluxes to a greater extent.

Most of the clays used for this purpose are imported from

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Germany and Belgium. There are American clays equal in every respect to the imported ones, but the American manufacturers are rather backward in adopting them. In this respect they are much like the potters, who prefer to use foreign materials. Many clays have been tested in this laboratory in searching for substitutes for foreign clays, and several have been located. It seems possible to find clays in this country which are equal to every class of foreign clays; we have received clays which are practically the same, both chemically and physically, to imported pot and crucible clays. One American substitute for German pot clay, known as 69-B clay, was developed and placed on the market several years ago by the Laclede-Christy Clay Products Company and has given excellent results.

TESTING TANK BLOCKS AND POT MIXES

TANK BLOCKS

This department is equipped with a crusher, pulverizer, pug mill and kilns. Experimental mixes are made up into block 4 in. by 4 in. by 8 in. The blocks are moulded, dried and burned in the same manner as the commercial blocks in factory. Ten blocks of various mixes are placed on end in a tank, which is built in the furnace. The tanks are four and a half inches deep, and of sufficient size to allow several inches space between blocks and also between tank walls and blocks. The furnace is equipped with a counter-weighted sliding door. The tank has an outlet through which the molten glass can be withdrawn. When the temperature of the furnace has reached the proper point, a stopper is inserted in the outlet of tank, and the tank is filled with window glass batch, the batch being heaped over blocks, so that when it is melted the tank will contain about four inches of glass. Window glass batch, without cullet is used, as its fluxing action is more severe than bottle glass batch, and less time is required to complete a test.

When action has ceased and the glass is clear, the stopper is removed, and the glass allowed to flow from tank. The stopper is then replaced, and the tank is refilled with batch. Glass is drawn twice each day, and the test is continued, until the blocks

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show decided wear along flux line, which occurs between two and four inches from the lower end of the blocks. After completion of tests, the blocks are removed from tank and compared. Some mixes will show a deep flux line, and in case it is an inferior mix, nearly the entire lower part of block will be destroyed. Other mixes will show a very faint flux line with only a slight loss. The regular factory tank block mix is used as a standard in these tests, and the new mixes are compared with it. Mixes found to be inferior to the standard are discarded, while the better ones are tested a number of times, using several blocks of a good mix in a test. Changes are made in percentage of grog, and size of grains in an endeavor to improve a mix.

From the results so far obtained, it is evident that the resistance to fluxing action depends more upon the physical structure of the block than the chemical composition. A block for tank purposes must possess a certain density, which prevents the penetration of the fluxes. Also a block must give a smooth wearing surface and dissolve slowly in the glass without causing stones. Some very pure non-plastic clays are attacked only slightly by the fluxes, but must be introduced in a very fine condition as otherwise the bond clay will dissolve, allowing the refractory clay to enter the glass, forming stones.

These highly refractory clays can be used in a body that will vitrify in burning, being much like a porcelain. This type of body is only slightly attacked and should give long service.

Mixes high in silica, in which pure silica was added to give 77 percent SiO_2 in finished product, gave the greatest loss, nearly the entire block being destroyed.

Mixes high in alumina also gave poor service.

The results obtained from the above two mixes were not due to composition entirely, especially with the high SiO_2 mix, as this block was comparatively porous and allowed the penetration of fluxing materials.

One trouble experienced with tank blocks is what is known as "honeycomb wear," the action of the fluxes giving the block a rough honeycomb appearance. This has been said to be due to a number of causes; such as the use of old tank or pot shell in a

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mix for grog, or the use of fresh grog which has been burnt too hard. It is not advisable to use tank or pot shell in a mix, as this material has absorbed some fluxes, especially if of a porous nature. This can be shown by allowing old shell to absorb moisture and then drying, when the alkalis will appear upon the surface. Of course, a vitrified body will absorb little if any fluxing materials but when a vitrified grog is used there is danger of getting stones in the glass, as the bond clay will be dissolved more readily, freeing the vitrified grains of grog.

The honeycomb wear of a block may be due to other causes, as it occurs in blocks which do not contain hard burnt grog or tank and pot shell. It is evidently caused by conditions existing in the tank.

In one factory, three tanks producing same grade of glass were built of exactly the same blocks. The blocks were made and burnt at same time, having same treatment in every way. One tank failed at the end of eight months with the blocks in a honeycombed condition. The other tanks gave many more months service, with the blocks in smooth condition and no indication of the honeycombed effect.

Laboratory tests have shown that blocks will be attacked much more rapidly and show the honeycombed wear when the temperature is not high enough for proper melting of glass batch, or when it is allowed to vary several hundred degrees.

Tanks equipped with glass blowing machines appear to give longer service than others. This is perhaps due to continuous operation at a constant temperature, without a shut down during the summer.

Before the introduction of glass blowing machines, a tank would be closed down several months during the summer, and during this period repairs were made, and new flux blocks inserted where necessary. With machines in use, the tank is operated until failure of the blocks. Ten months was considered satisfactory service, but with machines the blocks last as much as two years. The life of a block in a window glass tank is much shorter, and twenty weeks is considered excellent.

It is the usual practice among glass makers to consider the

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service secured from tank blocks in weeks or months. As one tank may produce twice as much glass as another of the same size, it seems that the proper way would be to charge the tonnage of glass produced against the blocks.

PLATE GLASS POTS

A series of mixtures were made of various clays with different sizes of grindings and percentages of burnt clays. All mixes were prepared in the laboratory as follows: Clays were mixed and put through the pug mill, then allowed to age and dry. When dry, the mixes were reground and pugged a second time, when they were ready to be made up into pots.

The pots were moulded by hand, being built up in the same manner as a commercial pot. The pots were allowed to dry slowly at room temperature, then before being used were placed on hot plate until absolutely dry.

Pots are eight inches in diameter, this size being found to be the most suitable and give the same results as larger sizes. Larger sized pots were tried, but were found to be inconvenient to handle and required too much space in the furnace.

Two types of furnace were used in which the pots were tested. One is a semi producer-gas fired furnace using preheated air; the other is a direct fired furnace of large grate area using coal for fuel. The necessary temperatures for glass melting were easily maintained. During the day, the highest temperatures were carried higher than was necessary to make good glass. During the night and on Sundays, the temperatures were allowed to drop, in order to make the tests as severe as possible. At times the temperatures were raised to the limit of the furnace to test the refractoriness of the mixes, but all were found to be sufficiently refractory.

A pot arch was constructed on one of the furnaces where pots could be heated in case any of those in furnace should fail, but it was only necessary to do this a few times, for in the majority of tests, all of the original pots remained to the end.

Eight pots were set in furnace for each test, pots being raw. When the furnace had reached the right temperature, and

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the pots were in the proper condition, they were filled with plate glass cullet. When the cullet was melted, each pot would be removed from furnace with tongs and the glass poured out. While out in the open air the pots were filled with plate glass batch, and then placed back in the furnace. At times the temperature of the outside air was below freezing, and the pots would get quite cool, but no trouble was experienced from checking or cracking.

Three melts per day were secured from each pot and at times, four melts. The average length of time, pots were in the furnace was twenty-five days. At least two pots in each test were the same as the pot mix produced in factory. This mix was prepared in the laboratory in order to have all pot mixes made under the same conditions.

After the completion of a test, the pots would be compared, the regular factory mix being used as a standard. As we know what results have been obtained with the factory mix by various plate glass factories, under commercial conditions, we are able to determine the approximate service that can be expected of other mixes tested with the standard.

Any pot mixes found not to be equal to the standard were discarded. Mixes found to be equal or superior were tested again, and new mixes inserted in place of the discarded pots. By this process of comparison and elimination, in time nearly all the pots in a test would be found to be equal or superior to the standard. In such a case the mixes were made up with different grindings and percentages of burnt clay in order to effect a possible improvement.

In the first tests some of the pots failed after a few melts, failure being due to cracks or inability to withstand fluxing action of glass batches. The last two tests were stopped after 46 and 47 melts, with some of the pots showing very little wear and no signs of cracks. They were equal to many more melts. The number of clays used in the first pots was two, while the later ones contained up to five different clays.

When thorough testing in the laboratory has shown a mix to be of value, larger pots are made and tested in a glass factory. In each case this has verified the results obtained in laboratory.

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Much depends upon the manipulation of the clays, the preparation of the mix, and the pot maker, but the care that should and must be exercised in drying, is perhaps of more importance than all other steps in the manufacture of a pot. The greatest strength is developed by proper drying, and on this depends the future life of the pot.

A plate glass pot must stand changes of temperature, must resist the action of fluxes, give smooth wear, and not cause stones in the glass.

Our tests have shown that the greatest wear on a pot from the fluxes occurs during the first few melts. After the fifth melt, or so, the action diminishes. This is caused by the pot becoming dense and approaching vitrification.

As with tank blocks, the life of a pot appears to be due more to its physical structure than the chemical composition. It must have a certain physical structure to resist corrosion and at the same time be free from cracking.

Two pot mixes having approximately the same chemical composition, but containing different types of clays, will not give the same service unless the physical structure of both are similar.

CLOSED POTS FOR LEAD GLASS

It has been found that a mix which is suitable for plate glass will not always answer for lead and other glasses made in closed pots. A certain chemical composition is necessary where lead oxides are used in batches.

The mixes for this class of pots are prepared in the same manner as the plate glass mixes, and the pots are built up by hand. In testing closed pots, it is necessary to ladle the glass out. The new mixes were compared with mixes of known value, and the tests resulted in developing several excellent mixes.

Research Department
Laclede-Christy Clay Products Co.
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THE LIMITS OF PROPORTIONS OF SODA-LIME GLASSES

F. GELSTHARP AND J. C. PARKINSON

We have conducted a number of experiments which make it possible to prepare a triaxial diagram, showing the approximate practical limits for soda-lime glasses which are of especial interest in the manufacture of plate glass; and it may also be applied to certain bottle glasses, table ware and window glass. But we wish it to be understood, that this diagram cannot be properly applied in the case of glasses containing considerable amounts of other materials, such as potash, magnesia, baryta, oxides of zinc, lead, manganese, iron, aluminium, or boric acid.

As preliminary work a study of the silicates of soda and lime was made. The silicates of lime have been carefully studied by several investigators, chiefly in researches on Portland cement. The published works show that the following silicates can be produced. These are all opaque crystalline substances:

$$3\ CaO\ SiO_2$$
$$2\ CaO\ SiO_2$$
$$CaO\ SiO_2$$

There is a eutectic between metasilicate of lime and silica which may be represented by $2\ CaO\ 3\ SiO_2$. It is possible that higher silicates than metasilicate are produced in the making of a soda lime glass, but they have not been identified.

The silicates of soda have received some attention, but not so much as the lime silicates; at least we have not been able to find the results of a complete investigation of these silicates. We therefore attempted to make some of them, so that we might feel more sure of the facts in referring to them.

Orthosilicate $2Na_2O\ SiO_2$ was prepared by melting together the molecular equivalents of sodium carbonate and silica in a platinum crucible. There seems to be no doubt that this silicate is produced, because no CO_2 remains in the melt; and since it has been shown that Na_2CO_3 does not dissociate (except to a very

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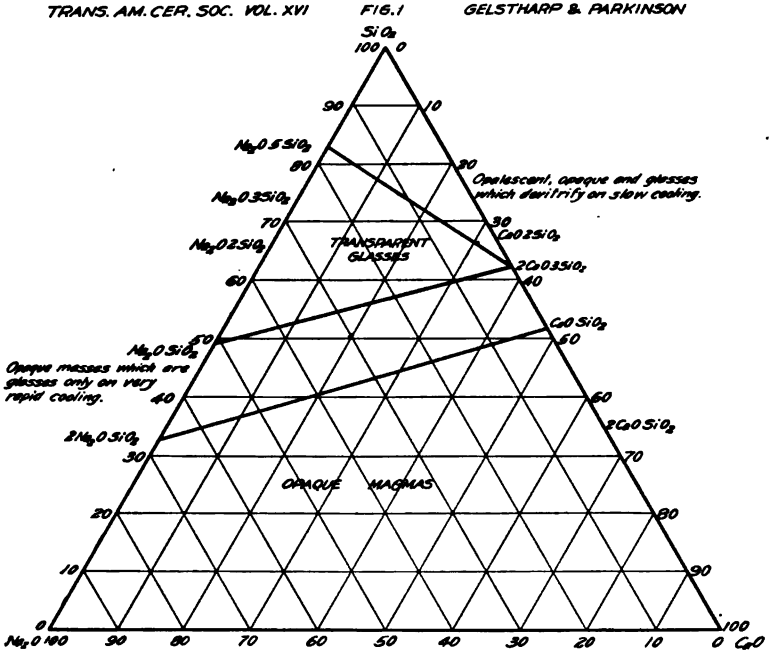
small extent), the reaction must have been complete. This silicate crystallizes very rapidly, so that a glass is not produced in the usual way, but by plunging the crucible in cold water the crystallization is prevented and a transparent glass results.

Metasilicate of soda $Na_2O\ SiO_2$ was produced in the same way from sodium carbonate and silica. This gave a transparent glass which crystallized readily on slow cooling.



Bisilicate of soda $Na_2O\ 2SiO_2$ was also made. The melt was quite clear as soon as the CO_2 evolution stopped. This is a transparent glass which does not crystallize on ordinary slow cooling.

Trisilicate of soda $Na_2O\ 3\ SiO_2$. In this case the evolution of CO_2 stops before a transparent glass is produced. Grains of silica may be seen suspended in the melt, which dissolves slowly to a transparent glass. This would tend to show that trisilicate of soda glass is most probably a solid solution of silica in bisili-

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cate of soda, and all the higher silicates, if they may be called such, are probably of the same order.

The silicates of soda seem to have the power to dissolve varying amounts of silica and lime silicates and still retain their transparency. Their tendency to crystallize increases in proportion to the amount of the lime silicates in solution, also as they become very rich in alkali, or saturated with silica.

Referring to the diagram we have prepared, we have indicated the position of the known silicates and those supposed to exist. In the lower portion of the diagram, below a line joining orthosilicate of soda and metasilicate of lime there are no glasses, only basic slags and infusible mixtures of silicates and bases. Above this line up to one joining metasilicate of soda and the eutectic $2CaO\ 3SiO_2$ transparent glasses are produced, only when very rapidly cooled; otherwise, they are opaque crystalline masses. Above the latter line, up to one joining the silicate of soda $Na_2O\ 5SiO_2$ and the eutectic, $2CaO\ 3SiO_2$, we have a triangular area in which transparent glasses proper are produced, which area includes those glasses possessing properties, which satisfy the technical demands for plate, window, bottle and other glasses.

Above this area to the apex of the diagram, transparent glasses can be made when they are very rapidly cooled. But on slow cooling, as in the process of annealing, crystallization takes place resulting in either opalescence, isolated crystals in a clear body, or the mass will be opaque. In this area above 85 percent silica, melting can not be done at ordinary furnace temperatures. When the lime exceeds certain limits, a perfect glass cannot be made unless sulphate of soda is present in the free state in the glass. If the attempt is made without sulphate of soda being present, the result invariably is the formation of a difficultly fusible white scum on the surface of the molten glass or around the edges of the pot, in which the melt is made. The glass under this scum may be perfectly limpid and clear, or it may contain flakes of this insoluble matter. This scum is not simply a silicate of lime, but a compound of silicate of lime and soda containing

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about 80-85 percent of silica, depending on the position on the diagram.

We have found that in order to have no white scum or flakes in a soda-lime glass in which sulphate of soda is not present, the molecular ratio of soda to lime must not be less than 2:1.

Figure 1. (1) The whole field is divided into opaque basic slags and infusible mixtures of silicates and bases; (2) transparent glasses only on very rapid cooling and otherwise opaque crystalline masses; (3) transparent glasses proper, including those of technical importance; (4) opalescent opaque glasses on slow cooling.

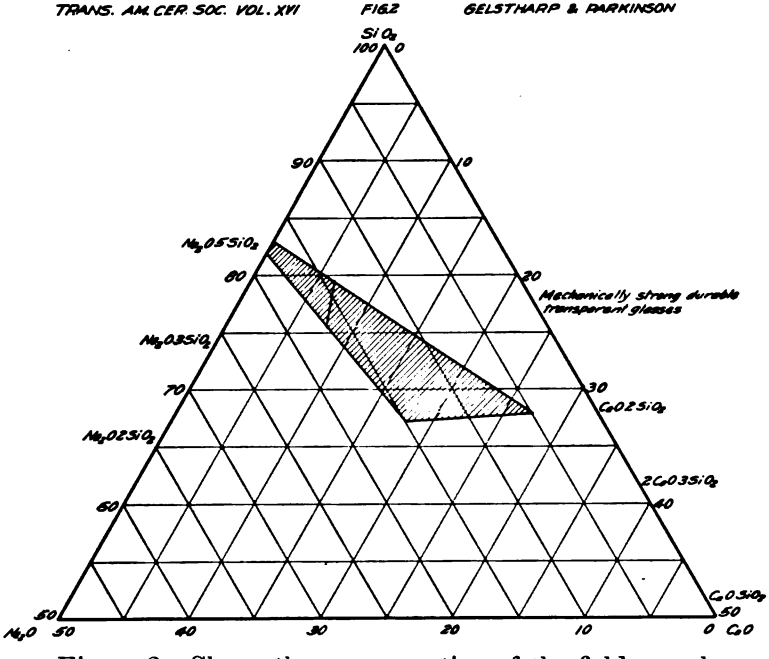

Figure 2. Shows the upper portion of the field on a larger scale on which the shaded area represents the position of good, mechanically strong and durable transparent glasses. The boundary line on the left cuts off all glasses containing soda in excess of 22 percent of the silica content. This line may be termed the limit of solubility. For some purposes this limiting

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line may be set to a lower standard, but for plate glass 22 percent is even much too low. The lower boundary line is one obtained by joining bisilicate of soda and bisilicate of lime. Below this the glasses for the most part are mechanically weak and have not sufficient resistance to withstand the action of dilute acids, water or the atmosphere. Moreover we find that these glasses devitrify or crystallize readily, the tendency towards crystallization being greater the lower the position.

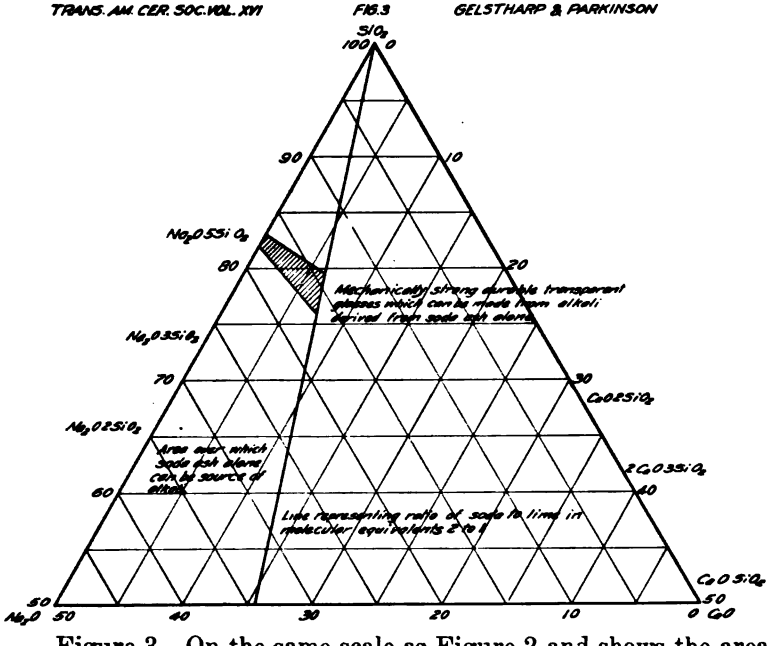

Figure 3. On the same scale as Figure 2 and shows the area over which soda ash alone can be the source of alkali. This area is a small portion of the shaded area shown on Figure 2, being cut off therefrom by a line drawn from the apex of the diagram to a point which represents a molecular ratio of soda to lime of 2:1 or a percentage ratio of 68.89 to 31.11.

The rule seems to hold out right down through the field, that all glasses made from soda ash alone, as the source of alkali on the left of this line, will be free from the white scum or

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flakes previously described; and that no perfect glasses can be made on the right of this line without producing this scum, unless saltcake is present in the glass. And we found that the farther we go in this direction, the greater is the amount of scum produced.

In order to obtain the foregoing information a large number of melting experiments on a fairly large scale have been made. The details of each experiment is omitted as unnecessary to the value of this paper.

The peculiar formation of white scum in soda-lime glasses made from soda ash, and the fact that when sulphate of soda is present there is a line cutting off glasses which devitrify or become opalescent, seems to us to indicate either that only certain definite silicates were produced under certain conditions, or that it is simply a case of the solubility of certain silicates of lime in silicates of soda, and that sulphate of soda aids this solubility in proportion depending on the extent of saturation of the silicate of soda with silica. It is our opinion that the active silicate of soda in ordinary glasses is the bisilicate and its solvent activity is diminished as its saturation with silica increases. The way in which the sulphate of soda assists, is most probably by decomposing certain compound silicates, which readily form during the melting (these we believe to be what constitute the white scum previously referred to) and reducing them to a condition in which they are soluble. This scum is less dense than the glass and tends always to rise to the surface. The sulphate of soda only reacts slowly with the sand at the early stage of the melt, and much remains in the metal till after the main reactions are over. As the temperature increases, the sulphate of soda becomes more active, and it then decomposes any higher silicates (which exist in the scum) and further, it also tends to rise to the surface as the temperature increases, so that so long as there is some sulphate present no higher silicates can exist.

Conclusions. First. We have defined the area over which good, mechanically strong and durable transparent soda-lime glasses can be made.

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Second. It is remarkable how small this area is of the whole field.

Third. Soda ash glasses can only be made successfully, with a limited proportion of lime. The proportion of soda to lime being as 2:1.

Fourth. The position of glasses which devitrify easily is indicated.

Fifth. We have found, that it is possible to make opalescent glasses using only the three components, silica, soda and lime.

Sixth. Sulphate of soda must be present in order to successfully produce glasses containing more than about 8 percent of lime.

Seventh. By the results of these experiments, the contention that definite silicates are formed in the making of glass is very much strengthened, and we feel that further study based on these results should enable one to work more intelligently on the problem of glass manufacture.

DISCUSSION

Mr. Shaw: Do I understand that this scum is the same scum that comes on sulphate glass under oxidizing conditions? Is it of the same chemical composition?

Mr. Gelstharp: No, the scum that you get from a case of that kind is chiefly sulphate of soda.

Mr. Shaw: Do you claim that you can not make a glass without that scum from soda-ash, silica and lime, if you do not have a ratio of soda to lime two to one?

Mr. Gelstharp: Yes.

Mr. Shaw: We made an experiment about two weeks ago with the molecular formula: $.5\,CaO\ \ .5\,Na_2O\ \ 2\,SiO_2$. That would fall outside of your ratio. They had no scum; we examined them carefully. It was a full sized batch of about fifteen to eighteen hundred pounds.

Mr. Gelstharp: Was the soda, ash or sulphate?

Mr. Shaw: It was a commercial material.

Mr. Gelstharp: We went into this matter very carefully,

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and in no case have we been able to make it without a scum around the edge of the pot, unless we had that ratio.

Mr. Shaw: It makes no difference whether you have oxidizing or reducing conditions?

Mr. Gelstharp: No difference.

Mr. Shaw: Well there might have been sulphate of soda in our experiments. I would like to ask Prof. Silverman if there are not a large number of causes of stone in glass?

Prof. Silverman: Yes, many of them.

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NOTE ON A METHOD OF INDICATING THE RATE OF SET OF LIME MORTAR

BY W. E. EMLEY

The final hardening of a lime mortar is accomplished by a chemical reaction between the lime and the carbon dioxide contained in the surrounding air. It follows therefore, that the hardening will begin at the surface of the mortar in contact with the air, and will proceed into the interior with more or less rapidity, depending upon the porosity of the mortar and such other factors as may influence the circulation of the air inside the mass.

The proportion of water originally present in the mortar is also of importance in determining the rate of set. Any excess moisture must be evaporated and removed by the air, and yet the mortar must not be left perfectly dry, for dry lime will not combine with dry carbon dioxide.

In order to study the influence of these various factors on the rate of hardening of lime mortar, it is necessary to have some means of indicating the manner in which the carbon dioxide acts. A chemical analysis will show the proportion of carbon dioxide present, but the fact that the mortar begins to harden on the outside shows that the carbon dioxide is not evenly distributed throughout the mass. This distribution of the carbon dioxide is equally important with the amount, in determining the strength of the mortar, and it is this factor which the following method is designed to indicate.

After a trial of some eighty organic dyes, Wool Blue R, made by the Berlin Aniline Works, was selected as giving the most satisfactory results. This dye is soluble in water forming a deep blue solution. When added to hydrated lime the color gradually fades out, until it is practically discharged at the end of one day. During the hardening of the mortar, the carbon dioxide restores the color to its original shade of dark blue. If a sample of mortar is treated with this dye and then examined after some time, that part of it which is in its original condition

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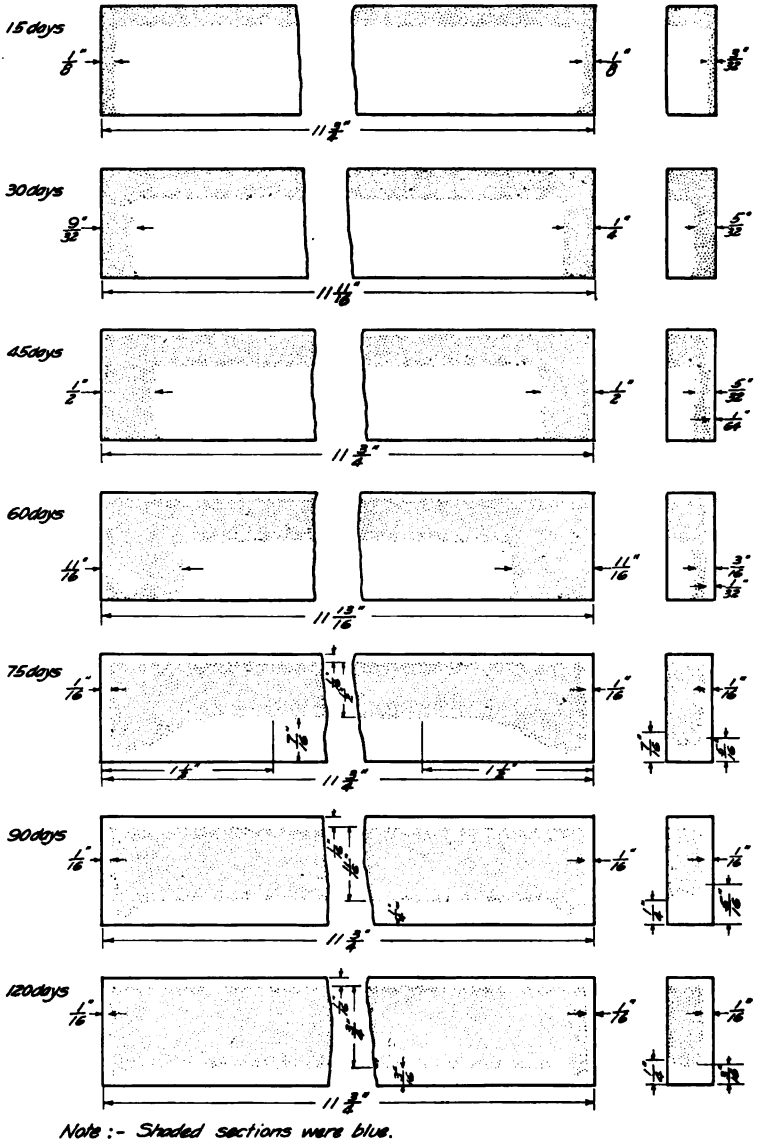
TRANS. AM. CER. SOC. VOL. XVI FIG. I EMLEY



Note :- Shaded sections were blue.

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will be colorless, while the part which has been attacked by carbon dioxide will be blue. The line of demarcation is sufficiently distinct so that its positon can be measured.

Seven bars, each 12 in. by 1 in. by 1 in., were made of lime mortar consisting of one part of a dolomitic hydrate and three parts of run-of-mine Ottawa sand. The water used in mixing this mortar had previously dissolved in it sufficient Wool Blue R to make a one-tenth of one percent solution. These bars were exposed to the action of the air in the room. Every fifteen days a bar was sawn in half lengthwise, and a picture of the interior was drawn as shown in the accompanying illustration.

It is believed that this method will prove valuable in studying the manner in which different factors influence the rate of set of lime mortars.

DISCUSSION

Mr. Greaves-Walker: I wish to ask Mr. Emley, whether he can tell me why lime mortar, when laid up in weather below zero and allowed to remain in a frozen condition, will set perfectly; but if the temperature goes above the freezing point before setting, the mortar can be picked from beneath the brick work with your finger. It crumbles and has no strength.

Mr. Emley: I am unable to answer that question, as I never had it called to my attention before.

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THE CLAYS OF EASTERN KANSAS[1]

BY PAUL TEETOR

On examining a geologic map of Kansas, we find that there are a number of geological formations outcropping in the eastern portion of the state, and especially along the territory extending into the state for a distance of 120 miles. There are seven different formations in this region, all of the Carboniferous period, one of the Mississippian, and the remainder in the Pennsylvanian. Within this region, known as the coal measures, are located nearly all of the clay working industries of the state.

The clays of this region are principally shales, red and buff burning, the buff burning shales containing a very high percentage of lime. There are also occasional deposits of surface clays; these as a rule are very high in lime and are very plastic and difficult to dry. In the southeastern portion of the state there are quite a number of clay deposits underlying the coal veins, which are known popularly as fire clays. In nearly every case where these have been tested, they have proven to be the most fusible clays in the state, although there has just recently been received at the laboratory a small sample of one of these clays from Cherokee County, which is of a refractory nature, and it may be possible that upon further testing it will be found to be a stone-ware clay.

In the Cherokee formation there is a large deposit of shale in the center of Cherokee County. Until recently this shale was used for the manufacture of drain tile; with a decrease in the local demand for this product, the company undertook to manufacture stiff-mud brick but found that the ware could not be dried without cracking, due to the excessive plasticity and drying shrinkage of the shale. A little farther north in this same formation in Crawford County, there is a very extensive deposit of yellow shale which is being manufactured into paving block and sewer pipe, producing a high grade of ware. This is a red burning shale and has rather strong tendencies toward kiln

[1] By permission of the Director of the Kansas State Geological Survey.

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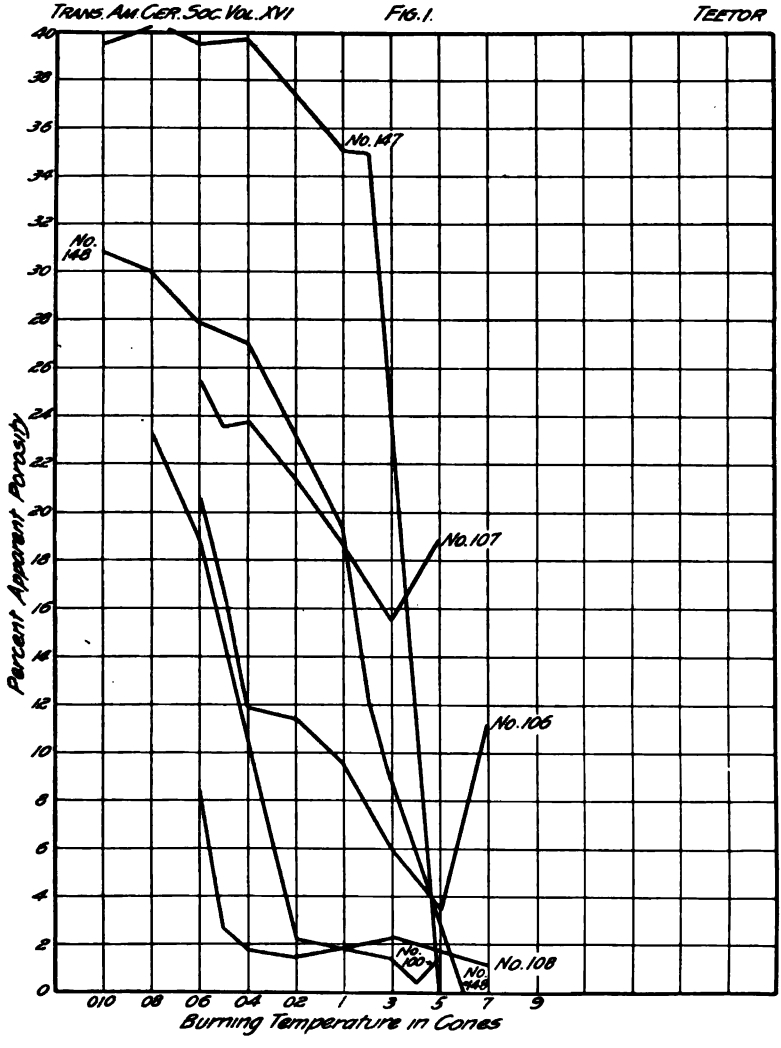

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marking. The best grade of sewer pipe is burned to cone 01. This shale has low plasticity, requires 17 percent water for proper working properties; it has a drying shrinkage of 4.5 percent and a burning shrinkage of 4.5 percent at cone 1. The porosity-temperature curve of this shale is No. 107 in Figure 1.

The rate of raising the temperature of the kiln while burning test pieces for porosity determinations was 20°C. per hour in every case.

A little farther west in the Marmaton formation in Montgomery County, there are several deposits of shale which are being utilized for the manufacture of paving brick, roofing tile and hollow building block. In Crawford County, there is a deposit of shale of the more fusible type; at cone 03 it is nearly vitrified and shows slight deformation. Dry press brick made from this shale has a burning shrinkage of 5.8 percent at cone 03.

In the Potawatomie formation in Montgomery County, there are several "shale mounds" which have become famous because of the very beautiful deep cherry red face brick which are being produced from them. Some of the "shale mounds" around Cherryvale are composed of two strata of shale, the top stratum being a yellow shale which burns to a buff color at cone 1. The top shale has a high content of lime, and the porosity decreases very rapidly above cone 2; at cone 5 the shale softens sufficiently to flow under its own weight. Curve No. 147 represents the porosity-temperature curve of this shale. The lower layer or blue shale in these mounds is red burning, and it is from this blue shale that the bricks referred to above are being manufactured. Curve No. 148 Figure 1 is the porosity-temperature curve for this blue shale.

There are shale deposits in Neosha and Allan Counties which are being utilized for the manufacture of building brick and hollow building tile: some of the deposits in Allan County are contaminated with lime pebbles.

In Miami County there is a deposit of blue shale being used for the manufacture of building brick and hollow ware. This shale requires 20 percent water of plasticity, has a drying shrinkage of 3.5 percent and a burning shrinkage of 6.74 percent

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at cone 1. The product manufactured from this shale scums badly due to the soluble salts present in the shale. Curve No. 106 is the temperature-porosity curve for this shale.

In Wilson County there are large deposits of shale in close proximity to each other and vary from the red to the calcareous buff burning. The calcareous deposits seem to vary quite materially, the composition changing very abruptly causing rather disastrous results in the burning. Often times one end of the kiln will have to be overburned in order to bring out the desired properties in the remainder of the kiln.

In the Douglas formation there are occasional outcroppings of shale from Caney in the southern portion of the state to Atchison in the northern part. So far as is known these are all red burning, and most of the deposits which are being utilized are used for the manufacture of vitrified paving brick. One of the shales occurring in Franklin County is an exceedingly plastic one, stiff-mud brick made on a small auger machine cannot be dried without cracking due to the auger laminations. The water of plasticity required is 21.7 percent. It has a drying shrinkage of 4.5 percent and a burning shrinkage of 8.75 percent at cone 1. Curve No. 108, Figure 1 is the porosity-temperature curve for this shale.

In the Shawnee formation in Shawnee County, there is a deposit of shale from which paving brick are being manufactured. A little farther south in Osage County, there is a very large deposit of shale, very fine grained and of an ocher like character. When heated to 300°C. the color changes from the yellow to red. The water of plasticity of the shale is 26.6 percent. The drying shrinkage is 5.5 percent and the burning shrinkage 9.26 percent at cone 2. Curve No. 100, Figure 1 is the porosity-temperature curve. There was a very urgent demand for a paving brick plant in this county, and as this was the only shale available, quite a bit of work was carried out to determine whether or not this deposit could be utilized.

The shale cracks during drying and cracks and warps during burning. The addition of 15 and 25 percent sand was tried and full sized paving block made from the mixtures. The crack-

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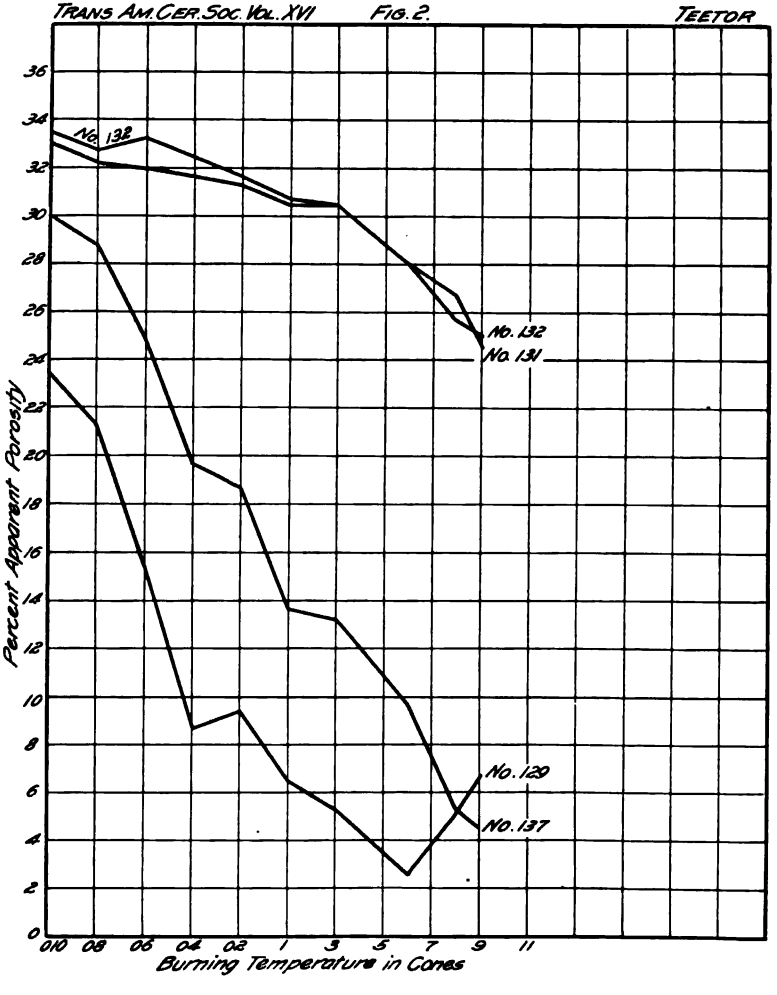

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ing was overcome, but the mixtures did not produce a tough enough body to pass the rattler test. Preheating was tried, the sample was preheated to 270 and 400°C. This preheating treatment improved the drying qualities but the drying loss was 50 percent. The rattler loss was 36.65 percent. These figures of course necessitated reporting that the shale was not suited for the manufacture of paving block.

No specific information has been worked out for the clays of the top Carboniferous or of the Permian; a little work was done on a deposit of Permian shale in Dickinson County, and it was found to be full of lime pebbles, the bricks "popped" due to the lime.

A little farther west in the Dakota formation in Ellsworth County there is quite a variety of clays. These are all of massive structure and are interstratified with the Dakota sandstone. A freshly cut surface in some of these deposits exposes a very beautiful variegated color effect, due principally to concretionary iron oxide. One of the red burning clays in this region which was tested was found to be too plastic for stiff mud wares. Dry press brick burned to a fairly good red color. The clay has a drying shrinkage of 5.0 percent and a burning shrinkage of 5.0 percent at cone 05. Curve No. 129, Figure 2 is the porosity-temperature curve.

Another red burning clay in this region, of which there is a large deposit, gets its red color from the concretionary iron oxide present. It is rather plastic, and stiff-mud wares made from it have a tendency to warp. It has a drying shrinkage of 5.26 percent and a burning shrinkage of 4.47 percent at cone 3. The red color does not develop to any extent until a temperature of cone 03 is reached. Curve No. 137 is the porosity-temperature curve for this clay.

In the eastern edge of Ellsworth County, a light colored clay outcrops in some of the larger hills. It, also, is a little too plastic for stiff-mud products such as brick. Dry press brick made from it burn to a beautiful light buff color, but are too porous and of insufficient strength to be used for structural purposes. The drying shrinkage is 3.12 percent with no burning

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shrinkage at cone 2. Curves No. 131 and 132 are temperature-porosity curves of two samples of this deposit. This is a very fine grained clay, rich in silica, it has a silica content of 72.78 percent and no lime or magnesia.

An attempt was made to utilize the clay for pottery purposes, it has very good working properties for both casting and throwing. A glaze was applied to the biscuit ware and matured at cone 4. All of the pieces shivered badly. In order to produce a denser and stronger body several mixtures of the clay with feldspar were made and fired to cone 7. The most promising mixture was 90 percent clay-10 percent feldspar. This mixture has a burning shrinkage of 6.0 percent and a porosity of 6.7 percent and develops a stoneware grey color. This mixture has been fitted with a glaze maturing at cone 05.

A series of engobes and glazes were applied to dry press brick made from this clay, but all the mixtures shivered.

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THE INFLUENCES OF CALCIUM AND IRON CHLORIDES PRECIPITATED IN A PORCELAIN BODY

BY B. S. RADCLIFFE

The production of vitrified red floor tile has given manufacturers considerable trouble. Practically, the only solution of the problem has been to secure a good red burning clay, and burn to a degree of vitrification such that the red color is not destroyed. In most instances, it has been found impossible to make red bodies that have less than four or five percent absorption, and in many cases the absorption is considerably greater than this.

Good red bodies can be made by mixing the proper amounts of feldspar and flint with "Helmstadter" clay, and burning to practically complete vitrification.

This clay is very fine grained, plastic, and is red in color. The original red color of the clay is only slightly altered during burning, up to the point when the porosity is reduced to about three percent. A higher temperature causes the red color to deepen and gradually change to dark brown and finally black. The deepening of the color begins about cone 6, and by cone 8 the body is dark brown to black. The burning qualities of this clay seem to be due to the fact that the iron is present in a highly disseminated state.

This investigation was made to determine whether uniform colors of iron in varying shades could be produced by precipitating the chlorides of iron and calcium in a body.

A cone 10 porcelain was chosen for the body. It is not considered an ideal one for the production of red tile, and one containing more ball clay in place of the china clay would probably be better, since it would have less porosity in the dry state and would require less fluxing action for complete vitrification on that account.

Procedure. The three corner bodies as shown on the tri-axial diagram were mixed by wet-grinding for five hours in a porcelain-lined ball-mill. The tri-axial group of 66 bodies was made by blending these three bodies.

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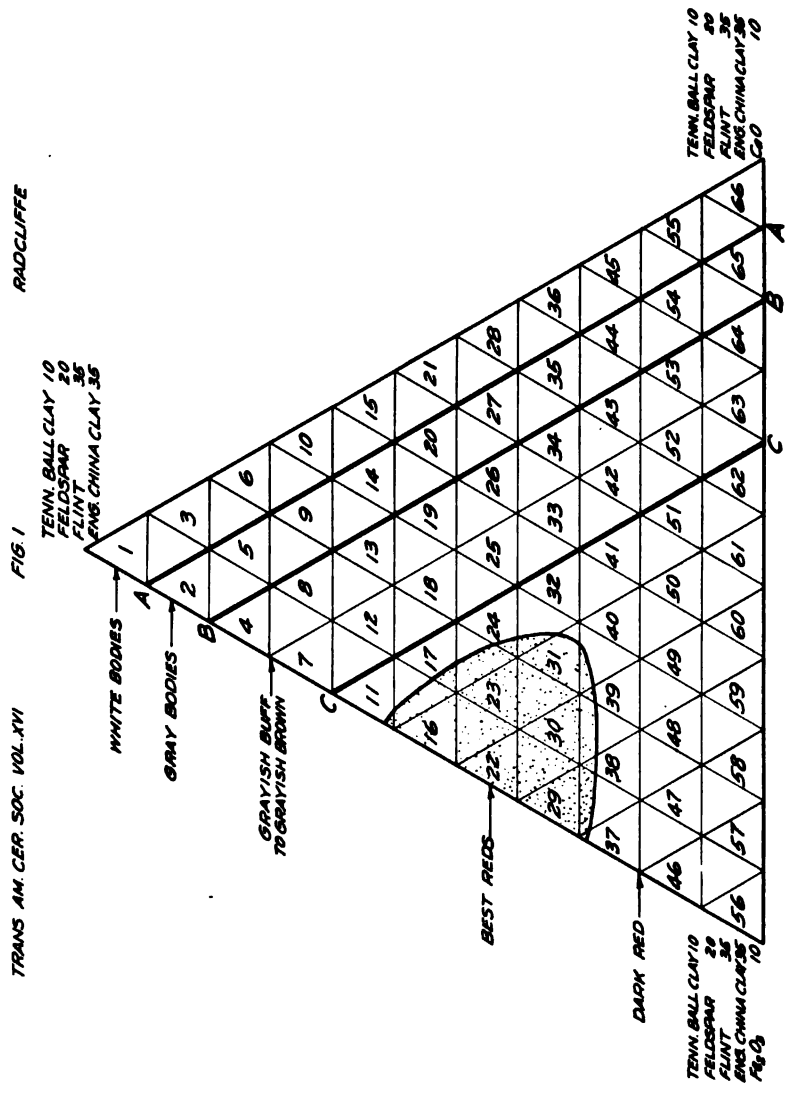

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The mixtures were put in fruit jars and shaken thoroughly so as to obtain uniform mixtures. The chlorides were precipitated by adding NH_4OH and $(NH_4)_2CO_3$ and shaking. The slips were allowed to stand for a day, after which they were poured into plaster molds. When the excess water had been absorbed the bodies were removed from the molds, and dried in an oven to 200°C. After crushing in a porcelain mortar, triangular floor-tile were made by the dry-press process, about 10 percent of water being used. They were burned to cones 5, 7, 9 and 11 in an open, down-draft, gas-fired test kiln.

Results. Those bodies high in iron were most plastic, and those high in lime were least plastic. This was shown both by the working properties of the bodies in the plastic state and by the strength of the dried tile.

Vitrification—None of the bodies were completely vitrified at cone 5, although those high in iron and lime were hard and dense, those high in lime being the hardest. At cone 7, all bodies containing over four percent of fluxes were vitrified. All bodies were completely vitrified at cone 9, those containing over 7 percent of fluxes being overburned.

Bodies containing 4 percent and over of fluxes were overburned at cone 11. The remainder retained their shape but had a glassy surface with the exception of 1, 2 and 3.

Color—Bodies free from iron burned white and were practical y uniform in color at vitrification.

Those containing 1 percent of iron were cream colored when burned under oxidizing conditions, but a good uniform gray color was obtained when the tile were reduced at the end of the burn. The lime had very little effect upon the color of bodies containing 1 percent of iron. Bodies containing 2 percent of iron were pink or light red at cone 5, above which temperature they changed to brownish buff with the exception of No. 4, which became dark yellowish gray.

Bodies containing 4 to 10 percent of iron burned red to dark red at cone 5. Those containing 4, 5 and 6 percent were still red at cone 7. The color was much deeper than at cone 5 and in-

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creased with increased iron. Two percent of lime did not affect the color of bodies containing 5 percent or over of iron.

The remainder of the series did not produce desirable colors for floor tile.

CONCLUSIONS

Uniform gray colors of pleasing shades can be made by precipitating 0 to 2 percent of iron in a porcelain body and burning properly.

Uniform red colors can be produced by precipitating 4 to 6 percent of iron in a porcelain body which, if burned properly, would not have more than 3 to 4 percent porosity.

Ceramic Laboratory,
University of Illinois

DISCUSSION

Mr. Parmelee: I should like to ask the reason for using calcium salt.

Mr. Radcliffe: Calcium chloride was added, because it is a soluble salt; and it was thought, that the intimate mixture of the calcium and iron obtained in this way, might throw some light on the cause of the varied color effect, produced by iron in different clays.

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NOTE ON THE PREPARATION OF FELDSPAR FOR THE CERAMIC INDUSTRY[1]

BY ARTHUR S. WATTS

The preparation of feldspar for the ceramic industry has been the subject of much discussion, but we have not as yet arrived at any standard for the grinding of feldspar. Furthermore, no specific data is available whereby a standard time of grinding can be chosen, for the reasons that the degree of fineness depends upon a number of factors, chief among which are the following:

Speed (i.e., r.p.m.) of the grinding cylinder. Weight of charge of pebbles in the cylinder. Proportions of the various sized pebbles in the cylinder. Weight of the charge of crushed feldspar in the cylinder. Degree of fineness to which the crude feldspar is reduced before being introduced into the cylinder. Condition of the crude feldspar as it is introduced into the cylinder, as regards temperature and content of moisture, and last but not least, the physical properties of the particular feldspar being ground.

Any difference in the conditions under which grinding is effected would seriously affect the degree of fineness. The user of feldspar is concerned only with the degree of fineness to which the material is ground, and the details of the grinding process need not interest him, except as they influence the quality or price of the material obtained. The proportion of the various sized particles obtained by a standard system of grinding, under uniform conditions and ground for stated lengths of time should be a valuable aid in choosing a standard degree of fineness. The increased pulverization obtained by grinding for longer periods should furnish data whereby the most practical degree of pulverization may be observed, and beyond which increased grinding does not produce proportionately increased pulverization.

To determine these data, a series of pulverized feldspar

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samples were obtained through the courtesy of Mr. C. E. Golding, manager of the Golding Sons Co. of Trenton, N. J. These pulverized feldspars were obtained by grinding their regular Maine feldspar for definite lengths of time in a standard ball mill. The following samples were taken:

The crude feldspar as it goes into the ball mill after being crushed by the buhr stone crusher.

The same feldspar after grinding 6 hours in the ball mill.
The same feldspar after grinding 8 hours in the ball mill.
The same feldspar after grinding 10 hours in the ball mill.
The same feldspar after grinding 12 hours in the ball mill.

CLASSIFICATION METHODS

In order to determine the percentage proportions of the different size of grain contained in these samples, the following system of classification was followed:

(a) Sieve classification. (b) Elutriator classification.

For the sieve classification, bronze cloth sieves were employed up to 330 mesh per linear inch, as is shown on the accompanying chart. For classification of the material passing 330 mesh sieve, the Schultz elutriator was employed. By regulation of the flow in the elutriator, the following classification was obtained in the different jars. With an overflow of 80 c.c. per minute, No. 1 jar has a hydraulic value of .0679, No. 2 jar has a hydraulic value of .0302, and No. 3 jar has a hydraulic value of .0075. The overflow from No. 3 jar furnishes a final classification. The size of grains obtainable with these different hydraulic values was determined by actual measurement of the classified material by the aid of the microscope. The classification was all effected in the wet way, and an abundance of water was employed to insure as perfect a classification as possible. In order to collect the fine slime which overflows from the last elutriator jar, the suspension was collected in a large jar and to this was added about 2 c.c. of concentrated hydrochloric acid. This causes the complete precipitation of the slime in about an hour, and the excess water can be siphoned off. The

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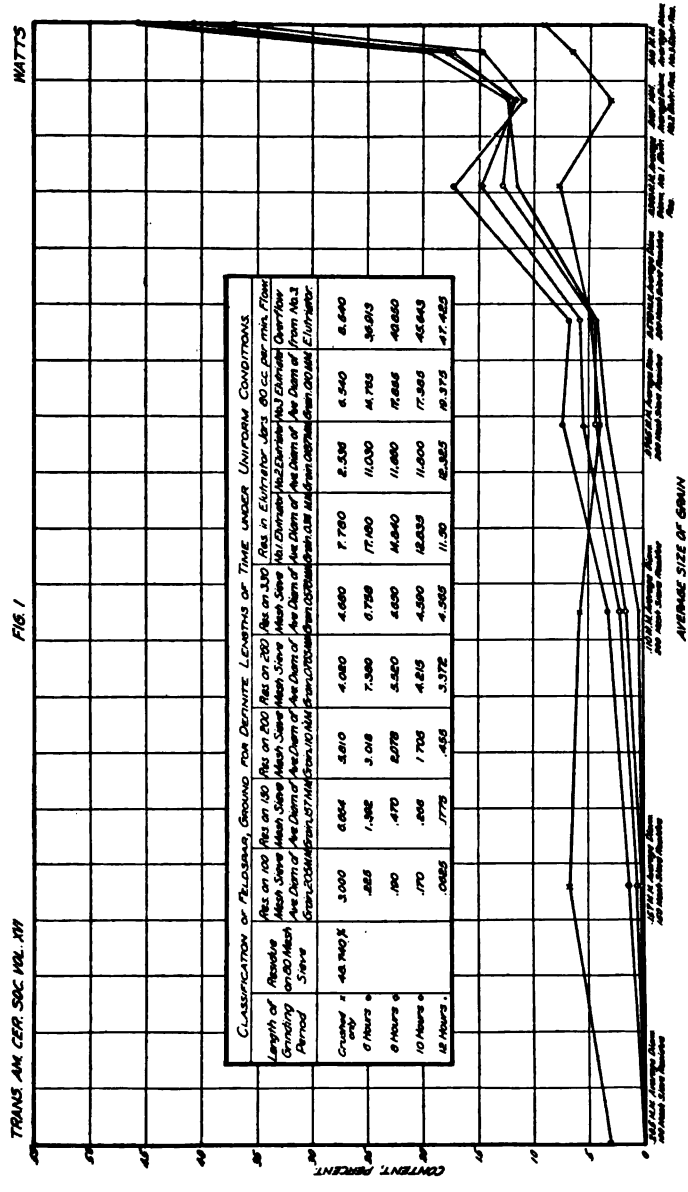

Classification of Feldspar Ground for Definite Lengths of Time under Uniform Conditions.											
Length of Grinding Period	Residue on 80 Mesh Sieve	Ras on 100 Mesh Sieve Ave Diam of Grain	Ras on 150 Mesh Sieve Ave Diam of Grain	Ras on 200 Mesh Sieve Ave Diam of Grain	Ras on 270 Mesh Sieve Ave Diam of Grain	Ras on 300 Mesh Sieve Ave Diam of Grain	Ras in Elutriator Jars 60 cc. per min. Flow No. 1 Elutriator Ave Diam of Grain	Ras in Elutriator Jars 60 cc. per min. Flow No. 2 Elutriator Ave Diam of Grain	Ras in Elutriator Jars 60 cc. per min. Flow No. 3 Elutriator Ave Diam of Grain	Ras in Elutriator Jars 60 cc. per min. Flow Overflow from No. 3 Elutriator Ave Diam of Grain	
Crushed only	48.740 %	.3000	0.054	0.810	0.020	0.690	7.780	2.535	0.540	0.540	
0 Hours	.885	1.382	3.018	7.380	6.758	6.650	17.150	11.030	14.755	35.813	
8 Hours	.190	.470	2.078	5.520	4.215	4.590	14.040	11.690	17.885	40.650	
10 Hours	.170	.205	1.705	4.215	4.590	12.035	11.800	17.565	45.643		
18 Hours	.0685	.1775	.455	3.372	4.565	11.30	12.385	16.375	47.425		

classifications were dried at 100°C. and weighed, after which the microscopic measurements were made.

A study of the accompanying chart shows that the increased pulverization, obtained by increased grinding under these conditions, is nearly proportional. The choice of a rate of flow for the elutriator was slightly out of accord with the other classifications, but this was gauged by the size of grains desired in the different classes. It is especially worthy of note that the ratios between the proportions of material removed by each classifier are regular.

The increased amount of pulverization obtained by twelve hours grinding over that obtained by ten hours grinding, when compared on the basis of material finer than .05 m.m. diameter, would indicate that maximum efficiency in grinding in this particular case is reached at about a ten hour grinding period. This of course holds good for this particular material and grinding process only.

DISCUSSION

Mr. Spier: I should like to ask Professor Watts what he means by six, eight, ten and twelve hour grindings.

Mr. Watts: I mean that the ball mill operated six, eight, ten or twelve hours, and was supposed to be grinding during that time.

Mr. Spier: Don't you think we should know the size of the particular ball mill, the amount of charge, the number of revolutions, and everything pertaining to it? Mills of different size with different sized charges and different numbers of revolutions, would give different results in the same length of time.

Mr. Watts: That is undoubtedly true. I stated in the paper that any difference in the conditions of grinding would seriously affect the result of grinding. The size of grains obtained by any standard system of grinding should be a valuable aid in choosing a standard degree of fineness. I am not discussing the process of grinding—whether it is better at thirty-two, thirty, twenty-eight or twenty-four revolutions per minute. That will depend on other things. The temperature at which the

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material goes into the ball mill will have a distinct influence. Other points which I tried to enumerate, are going to have a distinct influence also. If you are going to discuss the most efficient method of grinding feldspar, you are discussing one thing; if you are going to discuss the kind of material you want, no matter whether ground in a four foot ball mill and ground ten hours, or put in a six foot ball mill and ground five hours, I would say that this point has not come up in my work. It has been brought up but I am not able to handle it, because I have not at my disposal ball mills of various sizes.

Mr. Spier: Apparently I am misunderstood. I do not want to discuss the various processes, but I should like to know under what conditions these were obtained—the size of the mill and the amount of charge as well as the other details—so that we may use this as a criterion in arriving at what would be obtained in other cylinders, under similar conditions. I should like to know the size of the mill and everything pertaining to the experiment that Prof. Watts drew his conclusions from.

Mr. Watts: In regard to the data that you are asking for, I would say that I do not know whether these facts are obtainable or not. It would be practically imposible to obtain all this data from commercial feldspar grinding, because of the fact that many of these feldspars are the results of adjustments which the manufacturer has arrived at by a long process of elimination and testing, and which he considers vital to the success of his business, and he does not as a rule care to give this information to outsiders. In this case however he might be willing to do so. My object was not to show the work of some particular sized mill, it was to find the influence upon size of grain produced by grinding for different lengths of time.

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A NOTE ON THE REDUCTION OF Fe_2O_3[1]

BY C. S. KINNISON, BUREAU OF STANDARDS, PITTSBURGH, PA.

When Fe_2O_3 changes to a lower form, such as magnetite, Fe_3O_4, the conversion is characterized by a color phenomenon; magnetite *per se* is black, but this as a rule reacts, in the case of clays or similar mixtures, with the silica present to form ferrous silicates which may be dark brown to black in color.

In the present work, this color change was taken as the criterion of the reduction. The temperature at which this phenomenon takes place is, of course qualified by the dissociation temperature of Fe_2O_3. According to Le Chatelier, this reaction takes place at 1300°; according to White and Taylor at 1200°, and to P. T. Walden at 1350°C., the last named value representing probably the most reliable result. At this temperature the dissociation pressure reaches 160 m.m., which is equal to the oxygen pressure of the air. Ferric oxide cannot therefore exist above this limiting temperature, which corresponds to the reaction $3Fe_2O_3 \rightleftharpoons 2Fe_3O_4+O_2$. In carrying out the study, four different body mixtures were used: (a) North Carolina kaolin, (b) North Carolina kaolin and silica, the Al_2O_3 being to the SiO_2 as 1:5.5; (c) North Carolina kaolin and silica, the Al_2O_3 being to the SiO_2 as 1:9; and (d) a porcelain mixture of 15 percent Georgia kaolin, 26 percent North Carolina kaolin, 4 percent Florida kaolin, 20 percent feldspar, 33 percent flint and 2 percent fused magnesite. To each of these mixtures was added enough ferric hydrate to give 5 percent Fe_2O_3. The hydrate was obtained by precipitation with NH_4OH from a ferric chloride solution, the precipitate washed practically free from chloride before being added to the bodies. Mixing was accomplished by grinding wet for four hours. From these mixtures, small specimens about ¼ in. square by 1/32 in. thick were made and heated in a platinum resistance furnace to various temperatures. The furnace was carried up at the rate of 20° per minute up to within about 50° of the desired temperature from which point the rate was 5° per minute. The

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desired temperature was then maintained as nearly constant as possible, the maximum variation being 5°, for 1½ hours, this length of time having been found necessary for the complete development of the color on the surface of the specimens. At the end of this period the furnace was immediately opened and the specimen removed. In the preliminary work some difficulty was experienced in subjecting the specimen to a uniform temperature, due to rapid conduction of heat from the surface upon which the specimen rested. To obviate this difficulty a small refractory base consisting of kaolin and calcined alumina was made, the piece being about 2 in. long by ½ in. by ⅛ in., which could be readily inserted into the furnace. The real support of the specimen was of the same material, being about ½ in. by ½ in. by ¼ in. in size. In this a small platinum wire was coiled, one end extending up from the piece and terminating in a small loop upon which the specimen rested. This small wire was the only means of conducting the heat away; and there was apparently but very little difference in temperature between the top and bottom faces of the piece.

In all the bodies, the first color developed was of course, red. In the case of the first mixture, North Carolina kaolin, this color gradually disappeared, passing into a light cream at about 1200°. The latter color gradually darkened into a buff, the development of black then taking place rather abruptly at 1390°C. In this series, the buff effects due to alumina are clearly shown.

In body No. 2, the Al_2O_3 being to the SiO_2 as 1:5.5, the mass did not approach whiteness as closely as in body No. 1. This is acounted for in one respect by the fact, that the Al_2O_3 is lower in ratio to the SiO_2, in the latter mixture.

Yellowish buffs were noticeable which darkened as the temperature rose, a color change characteristic of ferrous silicate appearing rather sharply between 1360°-70°.

In the most silicious mixture represented by body No. 3, the color phenomena are similar to those of body No. 2. The red colors fade into pinks with increase in temperature, disappearing rather abruptly at 1280°C. The light color is replaced at 1300°C. by a rather dark buff, while the ferrous silicate color

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and glassy texture appears shortly above this point at 1310-20°.

The pottery body illustrates nicely the effect of fluxes on the coloring action of the iron. The buff effect of the alumina is obliterated by the formation of fused material at relatively low temperatures, at which the iron is not dissolved, but exists probably as suspended material, its coloring qualities being magnified thereby, and the specimen becoming more richly colored. Two series of colors are to be observed, one characterized by reds which is limited rather obscurely by the development of chocolates, (the second color series) due to the formation of fused material. As the temperature rises, the iron no longer remains in suspension but enters into solution. The ferrous silicate formation ensues at 1210-1220°, while at 1240° the mass is completely fused, and the coloring power of the iron greatly decreased by virtue of its solution.

TABLE I—COLORS DEVELOPED AT DIFFERENT TEMPERATURES

TEMP.	1	2	3	4
1100	Red	Red	Red	Red
1150	Lighter red	Lighter red	Lighter red	Darker red
1200	Cream	Light buff	Lighter red	Reddish chocolate
1250	Cream	Buff	Pink	Greenish brown glass
1300	Cream	Yellow buff	Brown	
1350	Speckled buff	Brown (1370)	Black	
1400	Black	Practically black	Black glass	

No light colors were developed in this body.

A hasty microscopic examination of these specimens by Mr. Klein of the Bureau of Standards failed to reveal the presence of any magnetic oxide. However, it is barely possible that some may have been present, but inasmuch as the color change seemed to be mostly a surface phenomenon, there exists the possibility that none was included in the tiny sample under examination.

At temperatures in the neighborhod of 1200° most of the material seemed to be glass, while as the temperature was raised

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up to 1300°, yellowish brown crystals became noticeable, but no black material could be observed. Only the kaolin mixture was examined in this way, because it seems most likely that, since there was no free SiO_2, magnetite would be more apt to be present. It does not seem probable that the magnetite would persist, at the temperatures involved in those bodies containing free SiO_2. The reduction under these conditions very likely results in FeO, which at these temperatures would at once combine with the silica to form ferrous silicate.

SUMMARY

1. The results of this work seem to show that within limits, the temperature of formation of the ferrous silicate is qualified by the $Al_2O_3 : SiO_2$ ratio; the smaller this value, the lower the temperature of formation, within the limiting ratios used.

2. Seger's work on the effect of Al_2O_3 in the production of buff colors is also verified by the results obtained, and we can say in agreement with him that, relatively considered, the lower the ratio of the alumina to the iron content, the lighter are the colors developed.

3. The coloring propensities of ferric oxide are both opposed and augmented by the presence of fluxes. At relatively low temperatures, where the amount of fused material is small, the color is intensified by the suspension of the iron particles. As the temperature is increased and more fused material is formed, the iron is taken into solution, and its coloring effect decreased. The colors developed are influenced by the extent of solution and this in turn by the composition of the body in question and the temperature involved.

4. In acid clays it is very likely that the transition of Fe_2O_3 to Fe_3O_4 and FeO takes place at lower temperatures than for more aluminous mixtures, corresponding to 1320°C., as compared with 1390°C. In mixtures containing large amounts of fluxes reduction is associated with solution, owing to the low viscosity of the iron silicate. This dissociation temperature is located at about 1210-1220°C. It is evident that the fluxes contribute towards the lowering of the transition point.

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It has been suggested by Mr. Bleininger that one of the possible applications of the facts brought out might be the use of ground calcined clay for the bedding of vitrified china bodies in place of the flint, since in this way the discoloring effect of the Fe may be minimized.

DISCUSSION

Mr. Lovejoy: I should like to ask Mr. Kinnison, what the composition of the first three clay mixtures are?

Mr. Kinnison: The first is North Carolina kaolin; the second, North Carolina kaolin and silica, the Al_2O_3 being to the SiO_2 as 1:5.5; the third, North Carolina kaolin and silica, the Al_2O_3 being to the SiO_2 as 1:9.

Mr. Lovejoy: Both colors you attribute to aluminium?

Mr. Kinnison: Yes.

Prof. Orton: I should like to ask whether there was any development of a particularly vesicular structure in connection with the experiments?

Mr. Kinnison: There was no marked vesicular structure. The change in appearance was only a surface phenomenon. There was a slight pitting effect on the surface, especially in the highly silicious materials. In body No. 1 containing no free silica, the color was black which seemed to be due to ferrous oxide.

Mr. Karzen: I should like to know how the ferrous silicate is obtained under reducing conditions, if they used oxidizing temperature.

Mr. Kinnison: We do not have reducing conditions; when the dissociation takes place, oxygen is expelled, and Fe_3O_4 remains. It is not necessary to have reducing conditions, as the expression is generally used, in order to obtain a reduced form of the material in question.

Mr. Karzen: The same thing takes place in using ordinary care as a practical proposition?

Mr. Kinnison: I should say that it would.

Prof. Orton: I should like to ask one more question. Is it your idea that in breaking down Fe_2O_3, oxygen gas is actually evolved? The structure of any well vitrified mass is practically

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glass-like under the microscope, that is if you make a cross-section of any body which has been fired at a temperature where vitrification occurs, the structure is largely glassy when viewed by transmitted light. If a gas is liberated in a body at this state, it is bound to form little blebs or glass vesicles. Does the breaking down of Fe_2O_3 produce this condition?

Mr. Kinnison: It was principally a glass with some crystalline material.

Prof. Orton: Then if a gas is liberated in the midst of a glassy solution, would it not make a vesicular structure?

Mr. Kinnison: Not necessarily. Not if the gas escapes through open pore spaces already present.

Prof. Orton: Would the gas bubbles escape at the temperature where this occurs?

Mr. Kinnison: Yes, I think it would. The specimen used is of a very porous structure, due chiefly to the shrinkage of the ferric hydrate on being dried. Any gas evolved would have ample opportunity to escape through the continuity of open pores formed in this way.

Prof. Orton: I, myself have known, many times, the development of vesicular structure in connection with the change of color of clay bodies, and have speculated more or less, as to the possibility of that gas, which causes the sponge-like structure to develop, being oxygen in the iron oxide set free when the Fe_2O_3 becomes 2FeO.

Mr. Kinnison: Of course these are conditions which would not apply to anything but experimental work. The iron was introduced as the hydrate merely to obtain as intimate a mixture as possible.

Prof. Orton: You do not think that the ferric hydrate persists except for a short time?

Mr. Kinnison: No, even in the drying some of it would be broken up.

Mr. Bleininger: I wish to say that the formation of a gas may precede vitrification proper, and while in many cases you would have opportunity for its escape, under many conditions you would not, depending upon the structure of the clay itself.

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Mr. Allen: Would not the size have an influence on the escape of the gas?

Mr. Kinnison: It would. We tried to use the smallest specimen possible.

Mr. Forst: Regarding the use of calcined clay instead of plain for china, I have made an experiment myself. I had a large series of glazes and put them on as small tile as possible. I was much afraid that the glaze would run off the edge of the tile so I imbedded the tiles in calcined clay. They came out all right but it bleached all the margin on the back of the tile. We could not read the printing on the margin at all. Therefore there is something in kaolin that bleaches whatever it comes in contact with.

Mr. Shaw: Does Fe_2O_3 exist in silicates at temperatures above 1400°?

Mr. Kinnison: Ordinarily, no.

Mr. Shaw: Suppose you put Fe_2O_3 in glass?

Mr. Kinnison: We would probably not use it at that temperature. It would tend to oxidize on cooling.

Mr. Shaw: How do you get the yellow color in glass under oxidizing conditions from iron?

Mr. Kinnison: Probably by solution of the iron.

Mr. Shaw: You get a green color or a tendency to yellow or white, and glass-makers attribute it in one case to Fe_2O_3, and in the other to reduced iron.

Mr. Kinnison: In what quantity?

Mr. Shaw: The quantity would be the same in both cases. If you have an oxidized condition you get a yellow color in an enamel or glass. I could take the same enamel or glass and reduce it to get a green color.

Mr. Kinnison: What temperature did you use?

Mr. Shaw: About 1350° or so.

Mr. Kinnison: At 1350° you ordinarily have a very small amount of ferric iron present. The effect of iron is also partially neutralized by the alumina present.

Mr. Shaw: That does not answer the question of the existence of iron in the two states in these two silicates. With no

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difference except the degree of oxidation or reduction in the two cases.

Mr. Bleininger: Did not the glass you are speaking of contain oxidizing agents?

Mr. Shaw: In the case where the yellowish color comes, yes, nitre or manganese.

Mr. Bleininger: In other words your oxygen pressure would be higher, would it not, and tend to prevent the action of reduction?

Mr. Kinnison: It would tend to maintain the iron in the ferric state.

Mr. Bleininger: You would have some excess oxygen, and according to the law of mass action this should tend to prevent the reduction of the ferric oxide.

Mr. Kinnison: But if you reduce the glass, the Fe_2O_3 is of course reduced also.

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ROOFING TILE SLIPS AND GLAZES

BY E. T. MONTGOMERY AND C. FORREST TEFFT, ALFRED, N. Y.

While historians tell us that glazed roofing tiles have been known to man for many centuries—the oldest examples dating back to a period even before the beginning of the Christian era—still it has been within only comparatively recent years that much attention has been paid to the subject. In this country, it has only been within the past ten or fifteen years that glazed tiles have been made in any quantity, or any particular attention paid to their quality from an architectural standpoint.

There are in use to-day, in the roofing tile industry, both the one and the two-fire process for firing glazed wares. In the one-fire process the ware must, of course, be glazed in the green state, and the slip or the glaze, as the case may be, must mature at the vitrification temperature of the clay used for the tile. In the two-fire process, the previously fired or biscuited ware is glazed and re-fired to a low temperature in the glost burn.

The advantages and disadvantages of these two processes have already been so thoroughly treated,[1] that any further discussion here will be unnecessary. Suffice it to say, that glazed tiles fired by either process should be fired in muffle kilns, in the clean atmosphere of a gas kiln, or else thoroughly protected by blocks from soot and ash where coal is used as the fuel.

As bright glazes are very seldom used, due to the strong reflection of light from their brilliant surfaces, the glaze needs of roofing tile manufacturers may be stated as follows: For the one-fire process, colored slips, dull or immature glazes, and true mats developing at about cone 02, taken as the average firing temperature for good shale roofing tile clays, may be used. For the two-fire process, the previously fired or biscuited ware is true mats developing at cones 010 to 07, may be used. A few good bright glazes to be used for special orders or special purposes may be added to both of these lists.

This present investigation was outlined for the purpose of developing suitable slips and glazes of the types mentioned, and which would fulfill the requirements set forth above.

[1] Manufacture of Roofing Tiles, Bull. 11, *Ohio Geological Survey*.

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The clay used for the trial pieces upon which the slips and glazes were tested was a local shale of fine quality, which was formerly used here by the Ludowici-Celadon Company. This shale is an outcrop of the great body of Devonian shale of the Chemung division, which stretches across the southern part of New York State from Lake Erie to the Hudson River. It is of massive structure and medium hardness, and disintegrates quite easily upon weathering. This clay was ground in a dry pan and screened. That used for the trials was ground to pass an 18 mesh sieve. It was worked up into a plastic mass, 20 percent of water being required, then thoroughly wedged and the trials pressed by hand in plaster molds. It has a drying shrinkage of two percent and a fire shrinkage of five percent. It burns to a dense body at cones 02 to 01 in the laboratory kilns.

COLORED SLIPS AT CONE 02

We will take up first colored slips for the one-fire process maturing at cone 02. Orton and Worcester[2] have very fully discussed the advantages and disadvantages of colored slip coatings. They do not cost any more than glazes, even though they require larger amounts of coloring oxides, because the base slip is very inexpensive. They have a wide heat range; they are free from the common troubles of glazes both in burning and upon exposure to atmosphere conditions; they do not become vitreous enough to stick in burning so the tiles can be allowed to touch each other; they give very fine soft color effects and reflect even less light than mat glazes; and finally, they can be made practically impervious to moisture so that they will not stain and discolor unduly.

About thirty different white base slips of various compositions, taken from a number of different sources, were tested. These were applied by dipping to the bone-dry trial pieces. The most vitreous, and in all respects the most satusfactory base slip developed was composed simply of 95 percent M and M English ball clay and 5 percent of any of the following fluxes: sodium carbonate, sodium chloride, borax, lead carbonate, flux No. 1 or flux No. 2.

[2] Bulletin 11, *Geological Survey of Ohio.*

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FLUX No. 1		FLUX No. 2	
Common salt	1	White lead	3
Sodium carbonate	1	Sodium carbonate	1
White lead	1		

They all worked about equally well. The slip composed of 95 percent ball clay and 5 percent NaCl proved to be entirely satisfactory, fitting the body perfectly and being steel hard at cone 02. It was also practically impervious, and was the slip selected as the base for the color trials.

A very pleasing light green was obtained by adding 10 percent of chromium oxide to the base, and a fine dark green by adding 20 percent of this oxide. In an attempt to get as deep a color with less oxide, several stains were made up. One contained 20 percent of Cr_2O_3, and when 10 percent of this stain was added to the base slip it gave only a very light sage green. This is a very pleasing color, however. A second stain was made containing 50 percent of Cr_2O_3, 20 percent of the stain in the slip gave as dark a color as 20 percent of Cr_2O_3 alone. A third stain containing 75 percent of Cr_2O_3 gave no better results than the one containing but 50 percent.

Good blues were produced, ranging from light to dark, by the use of from two to ten percent of cobalt oxide in the base slip.

A pleasing bluish green of about the same depth of color as that given by 10 percent Cr_2O_3 was obtained by adding to the base slip 15 percent of lead chromate and 2 percent of cobalt oxide.

Ten percent of copper oxide seemed to have no coloring effect in the slip.

Twenty percent of MnO_2 gave a dark chocolate brown.

A mixture of 20 percent MnO_2, 20 percent CoO and 10 percent Cr_2O_3 added to the slip gave a very dark blue-black.

A few other colors can undoubtedly be developed, and many variations of color and tone can be made by blends of those already cited. It may be said in general in regard to colored slip coatings, that large amounts of coloring oxide are necessary to give even medium colors. For the colors available, however, the colored slip gives a very delicate, soft, pleasing color effect.

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DULL GLAZES AT CONE 02

A few very good, immature glazes for the one-fire process maturing at cone 02 were developed, but the type of glaze did not prove reliable at this heat, being too easily effected by slight variations in the temperature of the kiln.

MAT GLAZES AT CONE 02

A very good mat glaze having a heat range of about cone 04 to cone 1 was developed for use on one-fire tiles. The formula and batch of the white base glaze is as follows:

$$\left.\begin{array}{l} 0.60\ PbO \\ 0.25\ CaO \\ 0.15\ K_2O \end{array}\right\} 0.35\ Al_2O_3 \ \Big\}\ 1.3\ SiO_2$$

BATCH

White lead	154.8
Whiting	25.0
Feldspar	83.6
Clay	51.6

Clay to be calcined before use in the glaze.

The batches of five very good colored mats for the same heat range are as follows:[3]

	DARK GREEN	MULLEN GREEN	BLUE	VIOLET	MOUSE BROWN
White lead	308.0	129.0	308.0	104.0	129.0
Whiting	50.0	20.0	50.0	34.8	13.0
Feldspar	166.0	84.0	166.0	83.0	84.0
Zinc oxide	0.0	12.0	0.0	5.2	6.8
Calcined kaolin	88.0	44.0	88.0	30.2	44.0
Flint	0.0	18.0	0.0	23.4	18.0
Fe_2O_3	7.0	1.0	1.0	1.3	0.0
CuO	20.0	3.0	7.0	0.0	0.0
CoO	0.0	0.0	12.0	0.3	0.0
Cr_2O_3	0.0	0.0	0.0	0.7	0.0
Seger pink	0.0	0.0	0.0	9.0	0.0
Florida kaolin	0.0	0.0	0.0	4.6	0.0
Tin oxide	0.0	0.0	0.0	3.3	0.0
NiO	4.0	0.0	0.0	0.0	7.7
$MnCO_3$	0.0	0.0	0.0	0.0	3.5

[3] From the notes of Prof. C. F. Binns.

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Taking up now the glazes required for the two-fire process, which must be used at cone 010 to cone 07, we have first:

COLORED SLIPS AT CONE 010-07

By adding up to 50 percent of white lead to the same slips used at cone 02 they can be made steel hard at cones 010 to 07.

DULL GLAZES AT CONE 010-07

A very successful type of glaze for this purpose is one which is dull from immaturity. To develop a suitable immature glaze at this temperature, a series was made up as follows:

$$\left.\begin{array}{l} 0.10\ K_2O(Na_2O) \\ 0.50\ PbO \\ 0.25\ CaO \\ 0.15\ BaO \end{array}\right\} 0.15\text{-}0.30\ Al_2O_3 \left\{ 1.5\text{-}3.0\ SiO_2 \right.$$

Series E 3 percent Cr_2O_3 added.

SiO_2	0.30 Al_2O_3	0.25 Al_2O_3	0.20 Al_2O_3	0.15 Al_2O_3
3.0	Nos. 1	Nos. 5	Nos. 9	Nos. 13
2.5	2	6	10	14
2.0	3	7	11	15
1.5	4	8	12	16

NOTE. These glazes were made with Cornwall stone.

This series, both at cone 010 and at cone 07, gave some very fine dull green glazes. At cone 07, Numbers 1, 2, 5, 6 were the best and at cone 010, Numbers 7, 8, 10, 11, 12, 14, 15 and 16 were all good vitreous, dull green glazes. Using glaze No. 11 as a base, good dull colors were obtained by adding 3 percent of CuO, $Na_2U_2O_7$, CoO and MnO_2.

MAT GLAZES AT CONE 010-07

For this type of glaze at cones 010 to 07 for two-fire tiles, one series was tried. It is as follows:

$$\left.\begin{array}{l} 0.80\ PbO \\ 0.10\ CaO \\ 0.10\ K_2O \end{array}\right\} 0.17\text{-}0.23\ Al_2O_3 \left\{ 1.0\text{-}1.4\ SiO_2 \right.$$

2 percent of CuO added.

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SiO_2	0.23 Al_2O_3	0.20 Al_2O_3	0.17 Al_2O_3
1.4	No. 1	No. 4	No. 7
1.2	No. 2	No. 5	No. 8
1.0	No. 3	No. 6	No. 9

Number 1 and Number 4 are good dark green mats at cone 010, or a little lower. Care must be exercised to use the exact formula of the feldspar in compounding the glaze, in order to get a mat surface. Calcining all or part of the clay is also desirable.

BRIGHT GLAZES

Bright clear glazes for either the one or two-fire process offer no difficulties, the ordinary raw lead glazes being used.

Dark reddish browns and blacks are easily prodcced by addition of Fe_2O_3 in the form of Albany slip, oxide of manganese and oxide of cobalt.

Green colors cannot be satisfactorily produced in these lead glazes by the use of copper oxide, except at very low cones, and quite large amounts of chromium oxide must be used to get a green color which is not destroyed by the red body color underneath.

CONCLUSION

In concluding this paper, the writers wish to emphasize a point which has been brought out rather clearly in our study of roofing tile glazes, and that is, that while slips give very pleasing and satisfactory results if large amounts of the coloring oxides are used, the dull glaze or mat of immaturity is a most promising type for a low temperature commercial roofing tile glaze.

DISCUSSION

Mr. Bleininger: I do not wish to criticise the paper, but my neighbor, Miss Farren, has raised a point of importance. She says, "Why don't you standardize your colors? It would be better to speak of a neutral brown than a mouse brown." I think that we should hear something about the colors, and how they are standardized.

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Mr. E. T. Montgomery: I should be glad to have some information on the subject. The common name is perhaps mouse color, rather than mouse-brown.

Miss Farren: In teaching our students at the Carnegie Institute of Technology, we are trying to lead them to use a better system of describing color. For instance, if they want to describe a color that is made of red and brown, they say red brown or brown red, according to which color predominates. If trying to describe a color with considerably more red than brown or vice versa, it can be described as red red-brown, etc. If trying to describe a color neutralized by its complimentary and leaning more toward one color than the other, they would say neutralized one-fourth, one-half or three-fourths, as the case might be. It may be neutralized either with black or its complimentary. We are opposed to their using expressions such as Nile green, or any terms derived from objects, as they are very misleading educationally.

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EFFECT OF CONSISTENCY AND AMOUNT OF SAND ON THE PROPERTIES OF LIME MORTARS

BY W. E. EMLEY

It is generally taken for granted, when making test specimens of lime mortar, that the consistency is of some importance as a factor in influencing the results obtained. There is at present no method in general use for measuring or recording the consistency. Most investigators merely add enough water so that the mortar "looks to be about right," and then record the percent of water used. But the properties of different limes vary so widely, that unless the original sample of lime can be exactly duplicated, the figure for the percent of water will be useless for anyone who tries to duplicate results. The same proportions of lime and water may give either a thin or a thick paste, depending upon the quality of the lime. Some investigators have assumed that comparable results can be obtained, if the same proportions of lime and water are used for all specimens. This frequently leads to the production of mortars which are so thick or so thin that they cannot be molded, or at any rate it takes no account of variations which may be caused by different consistencies.

It is commonly known that an increase in the proportion of sand in a lime mortar will cause a diminution of the strength. It is customary to use three parts of sand to one of lime in making test specimens, but it is desirable to know what influence a change in the proportion of sand will have on the final results.

In order to obtain the information required, the three constituents, lime, sand and water, were mixed in proportions varying by intervals of five percent. The consistency, shrinkage, decrease of weight, and crushing strength of the resulting mortars were measured.

The lime used was a dolomitic hydrate made by the Kelly Island Lime and Transport Company. This was mixed thoroughly by hand with run-of-mine Ottawa sand, after which the water was added, and again mixed by hand.

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TRANS. AM. CER. SOC. VOL. XVI FIG. 1 EMLEY

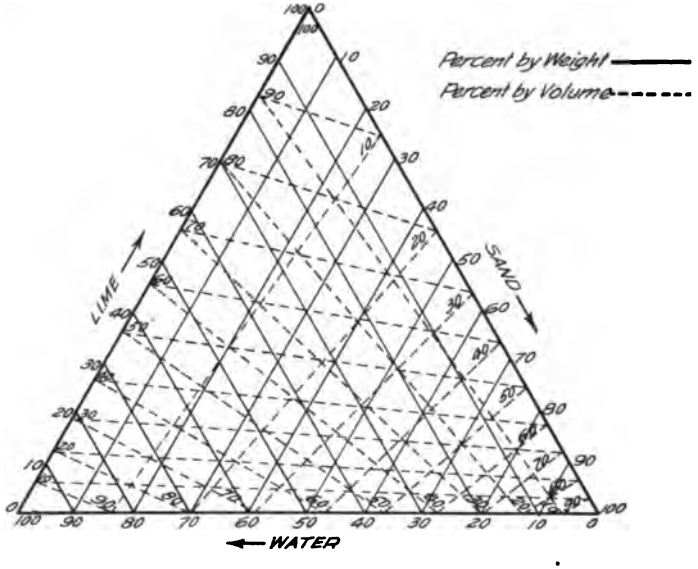
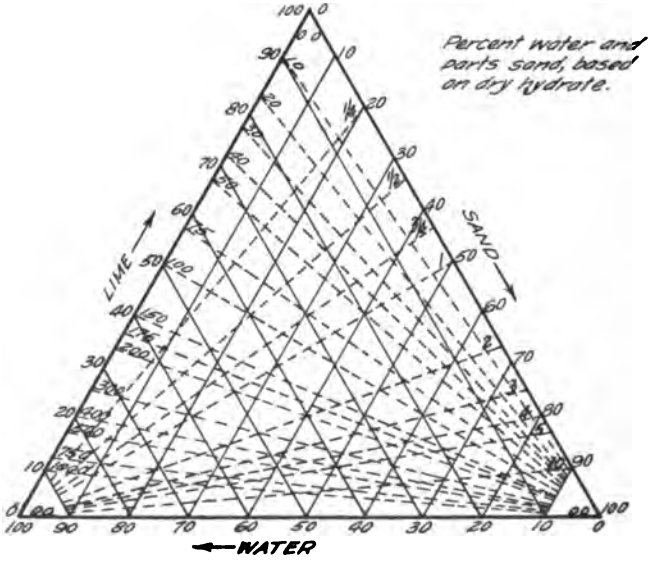


FIG. 2



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First, the apparent density of the material was measured by filling a vessel of known volume and weighing it. The mortar was merely shaken down in the vessel—not tamped—the idea being to get an approximate relation between the percent by weight, as used in the laboratory, and the percent by volume for practical use on the job. This relation is shown by Figure 1. If it is desired to express the proportions of the constituents as percent of water based on the lime, and as parts of sand, the diagram in Figure 2 will give the desired relation. The densities of the different mortars are shown in Figure 3.

To measure the consistency, three different instruments were used: 1. Chapman's instrument which was described in the *Proc. of the Amer. Soc. for Testing Materials,* 1913. This consists of a cylindrical mold made of hard rubber and split along one side only. The mold, mounted on a glass plate, is filled with the mortar, and is then raised one-half inch off the table and allowed to drop. The jar causes the mortar to settle in the mold, and the elasticity of the rubber permits it to spread open where it is split. The results obtained are given in Figure 4. 2. The plunger instrument was described in the *Transactions of the National Lime Manufacturers' Association,* 1911. It consists of a plunger, which is immersed in the mortar and then pulled out by a known weight. The time required to pull the plunger out is noted. This instrument is equipped with five plungers of different shapes: solid cylindrical, hollow cylindrical, conical, wedge-shaped, and spherical. The results obtained by using these plungers are shown in Figures 5, 6, 7, 8, and 9, respectively. (3). The Clark viscosimeter, described in the *Trans. Amer. Cer. Soc.,* 1913, consists of a hollow metal cylinder which is immersed in the mortar and then rotated at a constant speed. The power required to turn the cylinder is applied by means of an electro-magnet, and is therefore a function of the current used to excite the magnet. This current is recorded as a measure of the consistency. The cylinder may be replaced by a paddle carrying two square blades set parallel to the axis of rotation. The results obtained by this instrument are shown in Figures 10 and 11.

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The mortars were finally molded into two-inch cubes, which were permitted to harden in the air for 60 days, when they were measured and weighed, and their crushing strength was determined. This data is given in Figures 12, 13 and 14.

To show the use of the above curves, let us take a concrete example: A dolomitic hydrate will generally make a good mortar when mixed with its own weight of water and three parts of sand. The composition of such a mortar is shown by Figure 2 to be 20 percent lime 20 percent water and 60 percent sand by weight; or, from Figure 1, 40 percent lime, 20 percent water, and 40 percent sand by volume (opproximately). It will have an apparent density of between 1.9 and 2.0, Figure 3. When tested by Chapman's instrument, the rubber cylinder will spread about 15/16 in., Figure 4. In the plunger instrument, about 7/10 of a second will be required to pull out either the solid or the hollow cylindrical plungers, while the conical, wedge-shaped, or spherical will be useless. The consistency cannot be measured by the Clark instrument when either the cylinder or the paddle is used. A two-inch cube of the mortar, when 60 days old, will show a contraction of 5 percent of its original volume, a loss of about 13 percent of its original weight, and a crushing strength of 200 pounds per square inch.

A study of these curves will bring out the following points which are worthy of note: 1. In order that a mortar may have such a consistency that it can be used, its composition may be varied only within certain limits, but these limits are much wider than they are generally supposed to be. 2. A variation in the proportion of water in a mortar has a much greater influence on its properties than a similar variation in the proportion of sand. 3. As a means of measuring the consistency, Chapman's instrument gave excellent results. It covers the field completely, and is sensitive to small changes of composition. The solid or hollow cylindrical plunger is also quite sensitive. Its field is more limited, but contains most of the mortars commonly used in practice. The conical, wedge-shaped, and spherical plungers are useless. The Clark instrument is valuable on account of its extreme sensitiveness, when measuring the con-

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sistncy of a lime paste, but is useless for mortars. 4. Any variation in the composition of a mortar has a decided influence upon its properties. This may be emphasized by the actual results, as shown in Table I.

TABLE I

COMPOSITION BY WEIGHT			SHRINKAGE	CRUSHING STRENGTH
PERCENT LIME	PERCENT WATER	PERCENT SAND		
20	20	60	5	200
25	15	60	+.1	140
25	20	55	3	213
15	25	60	12	65
20	25	55	11	103
15	20	65	7	105
20	15	65	0	205

The consistency is evidently a very important factor which must not be neglected when measuring or comparing the properties of lime mortars. In fact, a comparison of the curves in Figures 4 and 14 indicates that the strength of a mortar is influenced more by its consistency than by its composition.

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TRANS. AM. CER. SOC. VOL. XVI FIG. 3 EMLEY

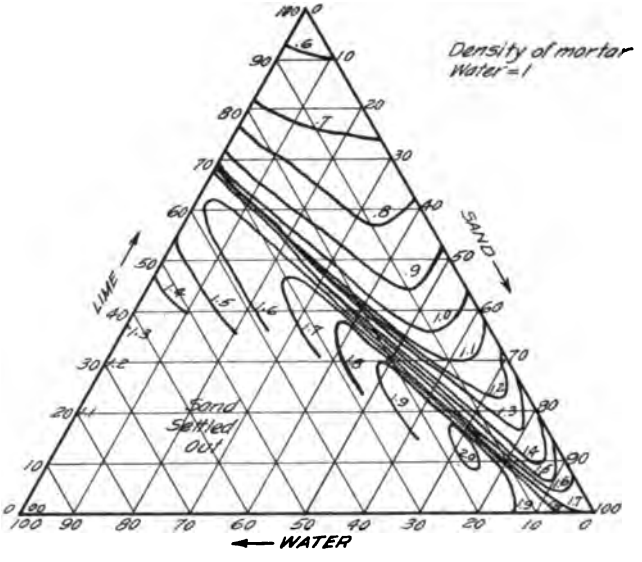
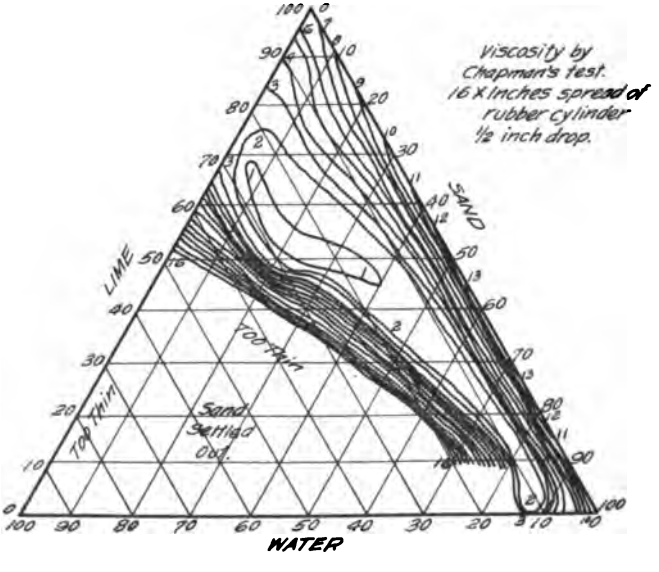


FIG. 4



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TRANS. AM. CER. SOC. VOL. XVI FIG. 5 EMLEY

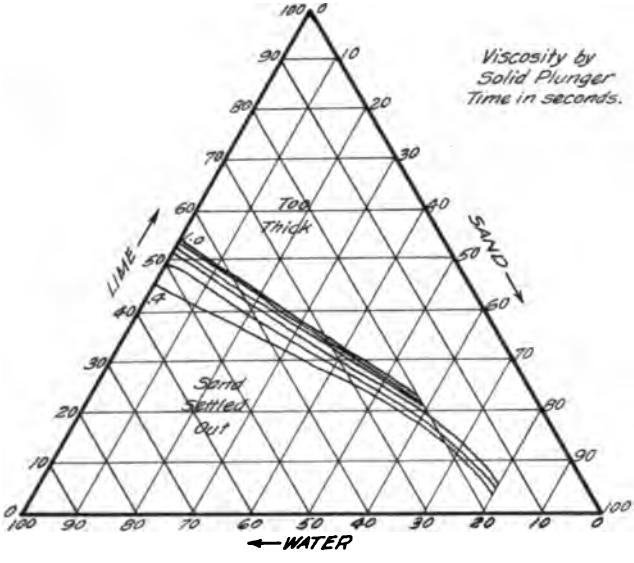
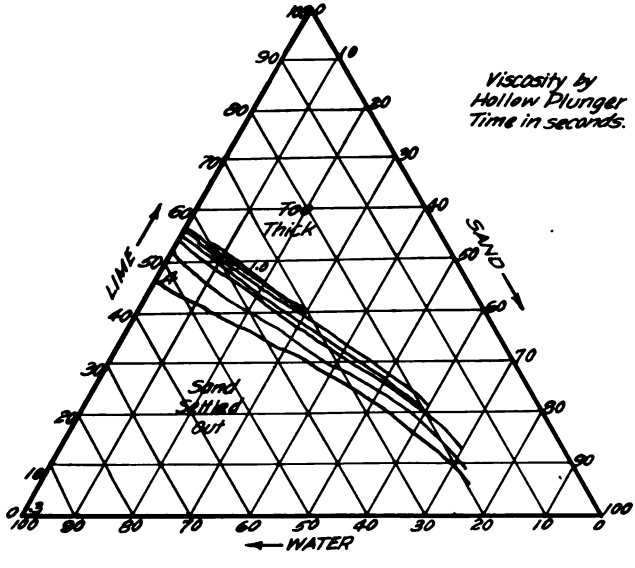


FIG. 6



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TRANS. AM. CER. SOC. VOL. XVI FIG. 7 EMLEY

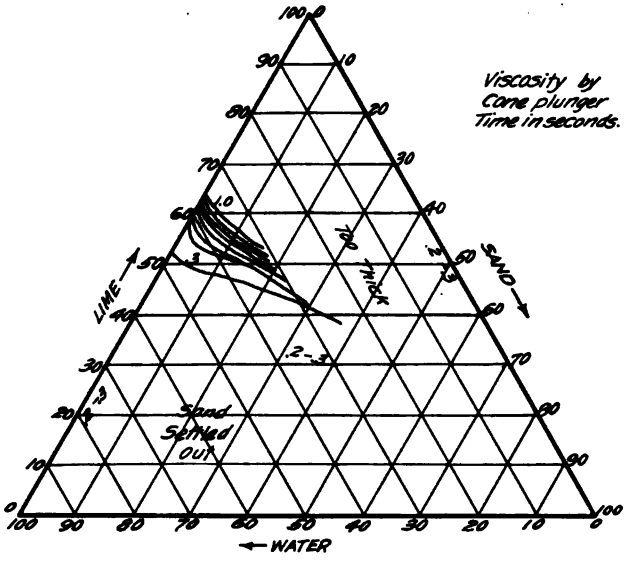
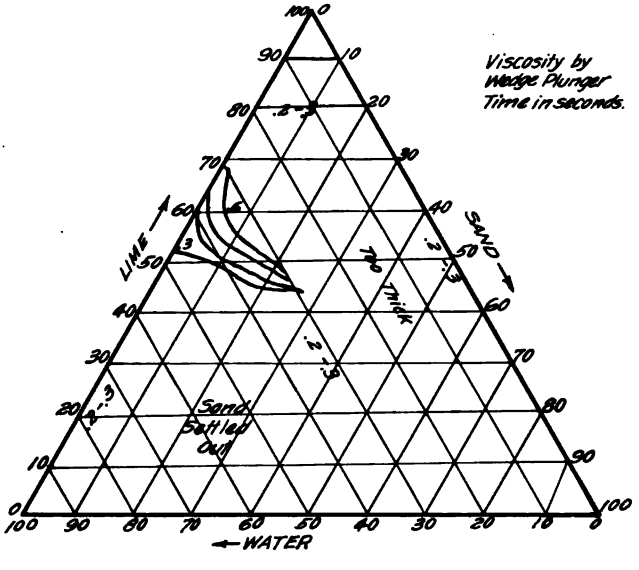


FIG. 8



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TRANS. AM. CER. SOC. VOL. XVI FIG. 9 EMLEY

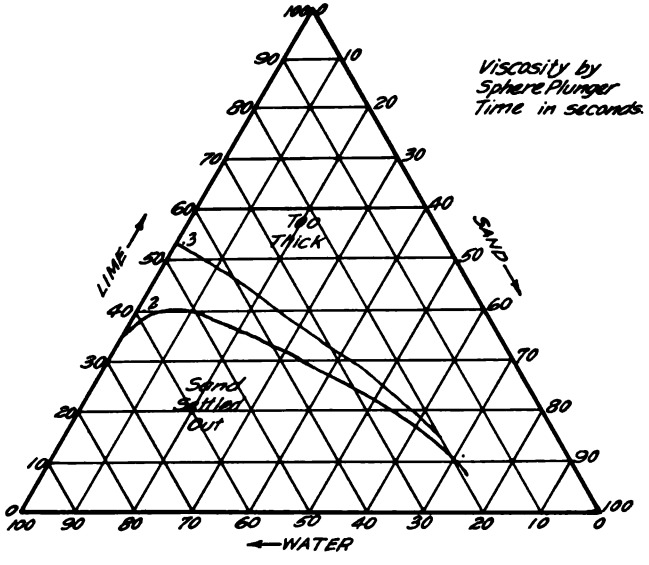
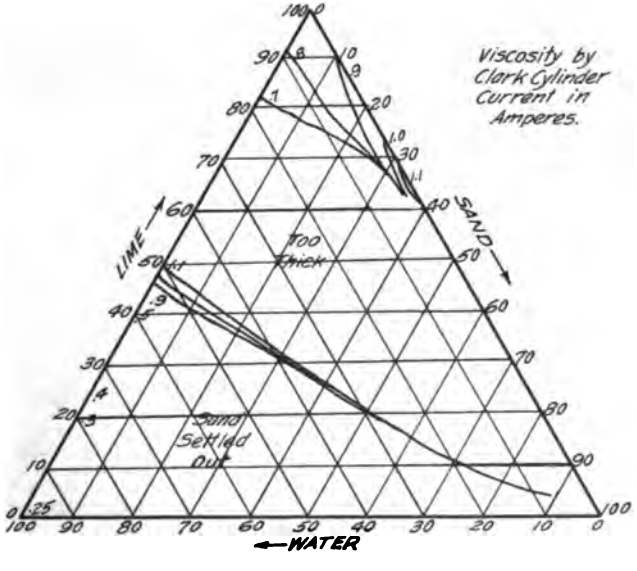


FIG. 10



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TRANS. AM. CER. SOC. VOL. XVI FIG. 11 EMLEY

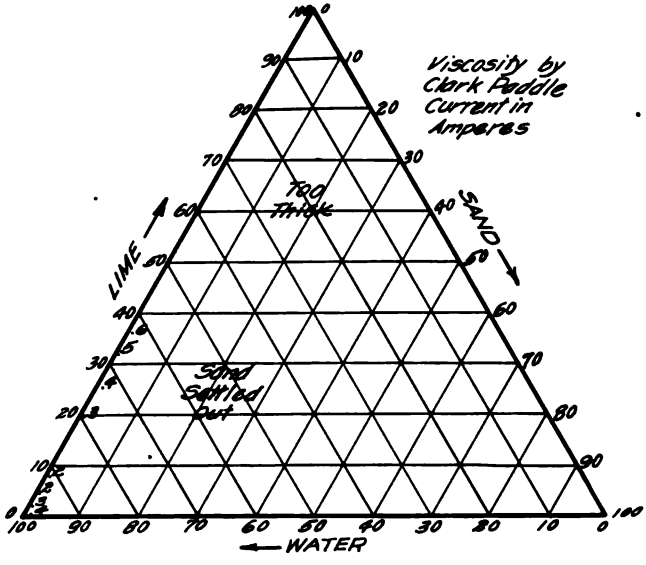
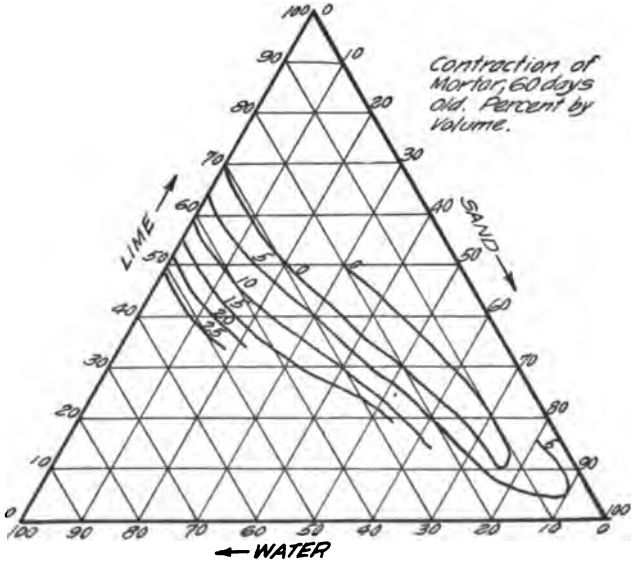


FIG. 12



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TRANS. AM. CER. SOC. VOL. XVI FIG. 13 EMLEY

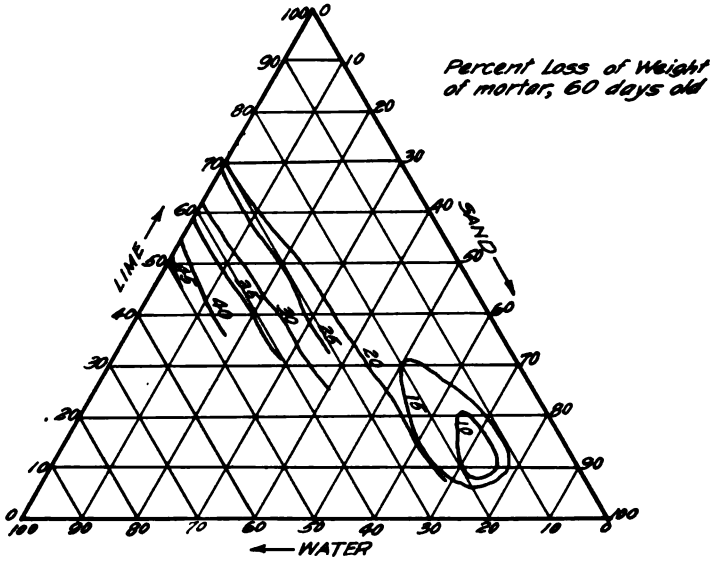
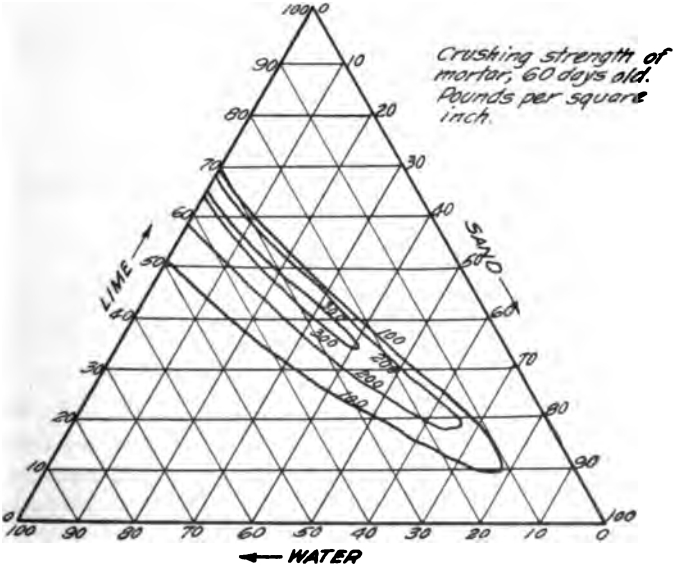


FIG. 14



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THE INFLUENCE OF SOLUBLE SALTS IN A CLAY UPON THE BEHAVIOR OF A SLIP AND GLAZE.[1]

BY MERLE A. COATS, ALFRED, N. Y.

The clays used in this investigation were terra-cotta clays from New Jersey, the serial numbers being 405 to 408 inclusive. These clays were first tested for soluble salts in the following manner: Each of the clays was agitated in a dilute NaOH solution in order to break up the particles of clay and to liberate the soluble salts. After settling, the clear liquid was tested for the soluble salts contained.

The following method was also used. A known weight of the clay was placed in a beaker, and a small amount of distilled water added. This was boiled for about two hours, keeping the amount of water constant by addition. The liquid was then filtered, evaporated to dryness and the residue weighed. This residue represents the salts from the clay. It was found that with the same clays, the amount of soluble salts liberated by the alkaline solution was greater than obtained with the distilled water, showing that the clay was more thoroughly broken up by the first method of treatment. The results of the determinations were:

TABLE I

CLAY NUMBER	AMOUNT OF SOLUBLE SULPHATES	AMOUNT OF SOLUBLE CHLORIDES
405	Free from sulphates	Cl present
406	Free from sulphates	.74 percent
407	.356 percent	Free from chlorine
408	Present	Free from chlorine

Clays Nos. 406 and 407 were selected for the body, as one of these was free from sulphates and the other was free from chlorides. The grog was passed through screens 10 and 30, saving what passed through the 10 and not the 30. The test pieces were

[1] Abstract of a thesis done at the New York State School of Clay-Working and Ceramics, under the direction of Professor Charles F. Binns.

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small tile, about 2 in. by 3 in. by ½ inch. The result of the body test is shown in the table:

TABLE II

BODY NO.	CLAY NO.	PERCENT OF CLAY	PERCENT OF GROG	DRYING QUALITY	ACTION IN FIRE AT CONE 6	
					COLOR	SHRINKAGE
1	406	75	25	Short	Cream	12.5 percent
2	407	75	25	Good	Cream	3.8 percent

Body No. 1 had too much shrinkage to be good, so body No. 2 was selected for the tests.

The underslips tested were as follows:

UNDERSLIP No. 1		UNDERSLIP No. 2	
English china clay	25	English china clay	50
English ball clay	6	English ball clay	50
Flint	20	Flint	60
Cornwall stone	45	Spar	130
German ball clay	6		
Sodium carbonate	1		

No. 1 came out a good white, at cone 6, while No. 2 was a cream color. Both covered well and were mature at that fire.

The following are the formulæ and the batch weights of the four corner glazes of the glaze series used:

Number 1 $\left.\begin{array}{l} K_2O\ 0.16 \\ CaO\ 0.40 \\ BaO\ 0.35 \\ ZnO\ 0.09 \end{array}\right\} : Al_2O_3\ 0.25 : SiO_2\ 2.5$

Number 2 $\left.\begin{array}{l} K_2O\ 0.16 \\ CaO\ 0.40 \\ BaO\ 0.35 \\ ZnO\ 0.09 \end{array}\right\} : Al_2O_3\ 0.25 : SiO_2\ 2.9$

Number 3 $\left.\begin{array}{l} K_2O\ 0.16 \\ CaO\ 0.40 \\ BaO\ 0.35 \\ ZnO\ 0.09 \end{array}\right\} : Al_2O_3\ 0.35 : SiO_2\ 2.5$

Number 4 $\left.\begin{array}{l} K_2O\ 0.16 \\ CaO\ 0.40 \\ BaO\ 0.35 \\ ZnO\ 0.09 \end{array}\right\} : Al_2O_3\ 0.35 : SiO_2\ 2.9$

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BATCH WEIGHTS

	No. 1	No. 2	No. 3	No. 4
Spar	89	89	89	89
Whiting	40	40	40	40
Barium carbonate	69	69	69	69
Zinc oxide	7	7	7	7
Kaolin	23	23	49	49
Flint	88	112	76	100

Glaze No. 1 came out a good mat in a preliminary burn, and was selected as the glaze to be used for the rest of the work, but later it proved to be more of an enamel and was not dependable as a mat glaze under the conditions of these tests.

It was found that the grog contained $CaSO_4$, amounting to .05 per cent.

Enough clay and grog were weighed up to make the test

TABLE III

MARK	$CaSO_4$ PRESENT PERCENT	CONE	SHRINKAGE	RESULTS
A	0.0	6	Normal	Glaze covered well and did not shiver
B	0.4	6	Normal	Glaze crawled
C	0.5	6	Normal	Glaze shivered and crawled
D	1.0	6	Normal	Glaze shivered and crawled
E	1.5	6	Normal	Glaze shivered and crawled
F	2.0	6	Normal	Glaze shivered and crawled
G	2.5	6	Normal	Glaze shivered and crawled
H	3.0	6	Normal	Glaze shivered and crawled
I	3.5	6	Normal	Glaze shivered and crawled
J	4.0	6	Normal	Glaze shivered and crawled
K	5.0	6	Normal	Glaze shivered and crawled

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pieces, and for the test marked "A" enough barium carbonate was added to neutralize the sulphate present. Test "B" contained only the sulphate already present in the body, but unneutralized. In the rest of the tests, $CaSO_4$ was added to the body in increasing percentages. The series is tabulated as follows together with the results obtained from this series using body No. 2, underslip No. 1 and glaze No. 1.

Although the glaze on all of the trials from the .5 percent content of $CaSO_4$ up to the 5 percent content shivered, it was incipient in all cases, and it did not increase with the increase of the sulphate. All of the glazes except on the first test piece "A" crawled very badly. This was due to the lack of bond between the body and the glaze caused by the coating of the soluble salt that formed on the surface of the piece in drying. All of the test pieces showed peeling when the glaze was first applied. There would be formed small cracks which did not heal over when the trial was burned. This was obviated somewhat by a careful application of the glaze.

The next series contained common salt, NaCl. It was added to the body in the same way as in the previous case, the same body being used with the same glaze and underslip. The results are shown as follows:

TABLE IV

MARK	NaCl PRESENT PERCENT	CONE	SHRINKAGE	RESULTS
A′	0.5	6	Normal	Glaze did not shiver but crazed slightly and crawled
B′	1.0	6	Normal	Shivered & crawled
C′	1.5	6	Normal	Shivered & crawled
D′	2.0	6	Swelled	See note
E′	2.5	6	Swelled	See note
F′	3.0	6	Swelled	See note
G′	3.5	6	Swelled	See note
H′	4.0	6	Swelled	See note
I′	5.0	6	Swelled	See note

NOTE: In all the rest of this series the glaze and body bloated under the influence of the salt so that it was impossible to ascertain just what the results were.

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In another series, the coating of salt which had formed on the surface in drying was removed. When these were burned the only effect noticed was that the glaze covered the test pieces better.

In the rest of the series the glaze used was a mat which had been developed in another experiment. The formula and the batch weights are as follows:

FORMULA GLAZE No. 42

$$\left.\begin{array}{l} CaO\ 0.40 \\ BaO\ 0.35 \\ ZnO\ 0.09 \\ K_2O\ 0.16 \end{array}\right\} : \quad Al_2O_3\ 0.31 \quad : \quad SiO_2\ 1.9$$

BATCH WEIGHTS

Whiting	40.0
Barium carbonate	69.0
Zinc oxide	7.0
Kaolin	39.0
Spar	89.0
Flint	38.0
Dextrine	1.5

In the next series magnesium sulphate was added in the same manner as in the previous tests. The glaze used was No. 42 and the underslip the same as before. The $MgSO_4$ did not cause shivering. The results are as follows:

TABLE V

MARK	PERCENT $MgSO_4$ PRESENT	CONE	SHRINKAGE	RESULTS
A″	0.5	6	Normal	No shivering
B″	1.0	6	Normal	No shivering
C″	1.5	6	Normal	No shivering
D″	2.0	6	Normal	No shivering
E″	2.5	6	Normal	No shivering
F″	3.0	6	Normal	No shivering
G″	3.5	6	Normal	No shivering
H″	4.0	6	Normal	No shivering
I″	4.5	6	Normal	No shivering

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In the next series which contains $CaCl_2$, the glaze and the underslip were applied to the leather hard body. The results are as follows:

TABLE VI

MARK	$CaCl_2$ PRESENT PERCENT	CONE	SHRINKAGE	RESULTS
A'''	0.5	6	Normal	Shivered slightly
B'''	1.0	6	Normal	No shivering
C'''	1.5	6	Normal	Shivered slightly
D'''	2.0	6	Normal	Shivered slightly
E'''	2.5	6	Normal	Shivered slightly
F'''	3.0	6	Normal	Shivered slightly
G'''	3.5	6	Normal	Shivered slightly
H'''	4.0	6	Normal	Shivered badly
I'''	5.0	6	Normal	Shivered badly and crawled

The next series contained ferrous sulphate. The same glaze and underslip were used giving the following results:

TABLE VII

MARK	$FeSO_4$ PRESENT PERCENT	CONE	SHRINKAGE	RESULTS
A''	0.5	6	Normal	Shivered
B''	1.0	6	Normal	Shivered
C''	1.5	6	Normal	Shivered
D''	2.0	6	Normal	Shivered
E''	2.5	6	Normal	Shivered
F''	3.0	6	Normal	Shivered
G''	3.5	6	Normal	Shivered

CONCLUSIONS

1. The addition of a soluble salt to a terra-cotta body will cause the glaze to shiver, hence, the presence of a soluble salt in a clay that is used for terra-cotta, is one source of the phenomenon of shivering.

2. The amount of salt that is present in a clay does not af-

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fect the degree of the shivering, as a small amount will cause it, and a larger amount does not seem to make it more serious.

3. The addition of a "fixer" as barium carbonate, will eliminate the trouble.

4. Applying the glaze to the leather hard body will not prevent the glaze from shivering.

All of the methods that were employed in these experiments were as near like the factory methods as it is possible to get experimentally. The fire in all cases was for 72 hours to cone 6 with an equal length of time for cooling. The glazes and the underslip were sprayed on. The bodies were mixed by hand and were hand moulded in plaster moulds.

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TERRA COTTA BODIES, SLIPS, AND GLAZES.[1]

BY GORDON D. PHILLIPS, ALFRED, N. Y.

The object of this series of experiments was to produce a satisfactory combination of body, slip and glaze to mature at cone 6-7 for architectural terra-cotta, and to study such points of interest as might come up in the course of such an investigation. Accordingly the work was outlined to secure: first, a satisfactory body as nearly as could be determined from the body itself without the application of slip or glaze; next, a good white slip to fit the body; and lastly, a suitable glaze to cover this slip so that ultimately the whole should enter into a perfect union which would not admit of peeling or scaling either before or after exposure to climatic conditions.

Plaster molds for trial blocks 2½ in. by 4 in. by ⅝ in. were made, and these same molds were used throughout the experiments. All bodies were made up by grinding the clays to pass through a 12 mesh sieve, mixing with the clay in the dry state the various other ingredients, putting the whole into a soak pit for 24 hours, and then pugging the mix by hand on a plaster slab. From the prepared body mix, the trials were made up by "pressing" in the plaster molds, removing it as soon as possible, and then tooling the faces down to a finished surface.

After a considerable number of preliminary trials with different body mixtures, the following body mix was decided upon:

	PERCENT
Perrine's stoneware clay[2]	79.5
Grog (12-45 mesh)	20.0
$BaCO_3$	00.5

The slip coating selected had the following composition:

	PARTS
China clay (M. G. R. No. 1)	25.0
Ball clay (Tenn. No. 1)	6.0
Cornwall stone	45.0
German ball clay	6.0
Flint	20.0
Sodium carbonate	1.0
	103.0

[1] Abstract of a thesis done at the New York State School of Clay Working and Ceramics under the direction of Professor Charles F. Binns.

[2] A New Jersey clay from H. C. Perrine and Sons, South Amboy.

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TABLE I—GLAZE SERIES

	Al_2O_3										
	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41
SiO_2 1.5	No. 1	No. 7	No. 14	No. 22	No. 31						
SiO_2 1.7	No. 2 (A)	No. 8	No. 15	No. 23	No. 32	No. 41					(C)
SiO_2 1.9	No. 3	No. 9	No. 16	No. 24	No. 33	No. 42	No. 51				
SiO_2 2.1	No. 4	No. 10	No. 17	No. 25	No. 34	No. 43	No. 52	No. 61			
SiO_2 2.3	No. 5	No. 11	No. 18	No. 26	No. 35	No. 44	No. 53	No. 62	No. 70		
SiO_2 2.5	No. 6	No. 12	No. 19	No. 27	No. 36	No. 45	No. 54	No. 63	No. 71	No. 78	
SiO_2 2.7		No. 13	No. 20	No. 28	No. 37	No. 46	No. 55	No. 64	No. 72	No. 79	No. 85
SiO_2 2.9			No. 21	No. 29	No. 38	No. 47	No. 56	No. 65	No. 73	No. 80	No. 86
SiO_2 3.1				No. 30	No. 39	No. 48	No. 57	No. 66	No. 74	No. 81	No. 87
SiO_2 3.3					No. 40	No. 49	No. 58	No. 67	No. 75	No. 82	No. 88
SiO_2 3.5						No. 50	No. 59	No. 68	No. 76	No. 83	No. 89
SiO_2 3.7	(B)						No. 60	No. 69	No. 77	No. 84	No. 90 (D)

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This slip was made up by grinding all save the sodium carbonate in a ball mill for two hours, lawning through a 120 mesh lawn, allowing to settle as much as possible, drawing off the surplus water and then stirring in the sodium carbonate to thin the slip. The slip was sprayed upon several of the dry body trials, and these were burned to cone 6 in the usual laboratory burn of 24 hours with rapid cooling. All these trials came out very satisfactorily. They were a good white and practically vitrified. There was no crazing, shivering or crawling, and the union between the slip and the body could scarcely have been improved upon.

Having developed a satisfactory slip the next proposition was to develop a good mat and a good, bright terra-cotta glaze to cover it. Using the R.O. content

$$\left.\begin{array}{l} K_2O\ 0.16 \\ CaO\ 0.40 \\ BaO\ 0.35 \\ ZnO\ 0.09 \end{array}\right\}$$

an extensive series was made up, covering all the probable area of varying alumina and silica. This series was burned fifty hours to cone 6 and then cooled slowly.

These glazes were made up by grinding A, B, C, D, No. 1 and No. 31 lawning through a 120 mesh lawn, drying them and then blending. The reason for placing A and C in the position in which they are, instead of at the extreme top, was that if C were placed at the top the necessary amount of clay would raise the silica content too high.

TABLE II—BATCH WEIGHTS

	No. 1	No. 31	A	B	C	D
Spar	113.12	113.12	113.12	113.12	113.12	113.12
Whiting	40.00	40.00	40.00	40.00	40.00	40.00
$BaCO_3$	68.95	68.95	68.95	68.95	68.95	68.95
ZnO	7.29	7.29	7.29	7.29	7.29	7.29
Clay	0.52	21.16	0.52	0.52	52.12	52.12
Flint	12.96	3.60	24.96	144.96	0.96	120.96
	242.84	254.12	254.84	374.84	282.44	402.44

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The materials from which all the glazes were made up were Eureka spar having the formula: K_2O, 1.3 Al_2O_3, 8.0 SiO_2, whiting, precipitated barium carbonate, zinc oxide, Florida kaolin and Eureka flint.

The method of applying all glazes was by spraying. First the slip was sprayed upon the dry body, then directly upon this the glaze until a water gloss began to appear. As soon as this disappeared another coat of glaze was applied, and this alternation continued until the glaze coat was thick enough.

This series gave good results. Area 1, 4, 31, 34 showed mat tendencies but all crazed, the crazing decreasing with the increase of silica and alumina. Area 41, 43, 61, 70, 78 and 85 showed promising mats, with 42 being very good. The remainder of the series varied through poor mats and immature bright glazes to a splendid bright glaze in No. 90. Number 42 as a mat and No. 90 as a bright glaze were the two best glazes of the series. As further proof of the advisability of using No. 42, another series was made up, covering part of the upper area omitted before. This was burned under the same conditions as the previous series. As No. 42 had shown a little tendency to flow and for fear that the zinc content was too high for stable color work, the RO was changed as follows:

$$\left.\begin{array}{l} K_2O\ 0.16 \\ CaO\ 0.44 \\ BaO\ 0.35 \\ ZnO\ 0.05 \end{array}\right\}$$

The following area was covered:

TABLE III

	Al_2O_3					
	.31	.33	.35	.37	.39	.41
SiO_2 1.7	No. 1	No. 5	No. 9	No. 13	No. 17	No. 21
SiO_2 1.9	No. 2	No. 6	No. 10	No. 14	No. 18	No. 22
SiO_2 2.1	No. 3	No. 7	No. 11	No. 15	No. 19	No. 23
SiO_2 2.3	No. 4	No. 8	No. 12	No. 16	No. 20	No. 24

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TABLE IV—BATCH WEIGHTS

	No. 1	No. 4	No. 21	No. 24
Spar	113.12	113.12	113.12	113.12
Whiting	44.00	44.00	44.00	44.00
$BaCO_3$	68.95	68.95	68.95	68.95
ZnO	4.05	4.05	4.05	4.05
Clay	26.32	26.32	52.12	52.12
Flint	12.96	48.96	0.96	36.96
	269.40	305.40	283.20	319.20

From this series the desired results were obtained. All were mats, but the area No. 1, No. 4, No. 7, No. 6, No. 9 were slightly crazed. Numbers 10 and 14 were beautiful, soft, silky, white mats, 14 being slightly smoother than 10. Accordingly this glaze, No. 14, was selected for color work.

It has the formula:

$$\left.\begin{array}{l} BaO\ 0.35 \\ K_2O\ 0.16 \\ CaO\ 0.44 \\ ZnO\ 0.05 \end{array}\right\} Al_2O_3\ 0.37 \quad : \quad SiO_2\ 1.9$$

Oxygen ratio 1.8

BATCH WEIGHTS

Spar	113.12
Whiting	44.00
$BaCO_3$	68.95
ZnO	4.05
Clay	41.80
Flint	17.76

It was found that .5 percent of dextrine was necessary to make these glazes adhere well, but it was later determined that by replacing 20 percent of Florida clay with Tennessee ball clay equally good results could be obtained without the use of dextrine.

The next step was to make up a number of stains as follows:

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STAINS

DARK BROWN. No. 1, CONE 1

Ferric oxide	80.0
Chromic oxide	76.2
Alumina	206.0

LIGHT BROWN, No. 2, CONE 1

Ferric oxide	160.0
Chromic oxide	152.0
Alumina	204.0
Zinc oxide	648.0

RED BROWN, No. 3, CONE 1

Ferric oxide	160.0
Chromic oxide	152.0
Zinc oxide	389.0

DARK GREEN, No. 4, CONE 7

Chromic oxide	27.0
Cobalt oxide	5.0
Cornwall stone	15.0
Zinc oxide	28.0

LIGHT GREEN, No. 5, CONE 4

Chromic oxide	18.5
Niter	24.7
Flint	20.0
Whiting	20.0
Fluorspar	12.0
Calcium chloride	12.0

DARK BLUE, No. 6. CONE 7

Cobalt oxide	80.0
Alumina	102.0

LIGHT BLUE, No. 7, CONE 7

Cobalt oxide	80.0
Alumina	204.0
Zinc oxide	81.0

RED, No. 8, CONE 4

Barium chromate	5.56
Red lead	4.20
Whiting	97.68
Niter	1.00
Tin oxide	167.85
Flint	67.34
Boric acid	.56

PINK, No. 9, CONE 4

Whiting	300.00
Tin oxide	149.00
Flint	60.00
Lead chromate	6.46

PURPLE BLACK, No. 10

Cobalt oxide	10.00
Manganese dioxide	90.00

BLUE SLATE, No. 11, CONE 7

Cobalt oxide	80.00
Manganese dioxide	160.00
Alumina	250.00

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In all cases the insoluble materials were intimately ground in a ball mill, and then the soluble salts of the batch in solution poured over the mix, and the whole evaporated to dryness. This mix was then calcined to the cone indicated, reground very finely, and then carefully washed free from sulphates and dried.

Trials were made up with varying portions of each stain to determine how much of each stain was necessary to obtain proper color in the glaze.

TABLE V

STAIN NO.	PERCENT NECESSARY
1	5 percent
2	3–4 percent
3	5. percent
4	4 percent
5	5 percent
6	3 percent
7	3 percent
8	7 percent
9	7 percent
10	2 percent
11	3 percent

The colored mats, more especially the blues, showed decided crystallization almost visible to the naked eye.

After this, another more extended series was made up using the stains in combinations basing the amounts of each upon the results of the first colored series.

TABLE VI

AMOUNTS OF STAINS	COLOR OF BURNED TRIALS
5 percent, No. 1	Brown
3 percent, No. 1 3 percent, No. 2	Red-brown
3 percent, No. 1 3 percent, No. 3	Deep red-brown
3 percent, No. 1 2 percent, No. 4	Gray-green
3 percent, No. 1 3 percent, No. 5	Greenish brown
3 percent, No. 1 1 percent, No. 6	Slate
3 percent, No. 1 1 percent, No. 7	Slate
3 percent, No. 1 4 percent, No. 8	Red
4 percent, No. 2	Yellow-brown

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2 percent, No. 2, 3 percent, No. 3	Red-brown
2 percent, No. 2, 2 percent, No. 4	Gray slate
2 percent, No. 2, 3 percent, No. 5	Brown
2 percent, No. 2, 1 percent, No. 7	Blue-gray
2 percent, No. 2, 4 percent, No. 8	Red
2 percent, No. 2, 4 percent, No. 9	Pink
5 percent, No. 3	Red-brown
3 percent, No. 3 2 percent, No. 4	Gray slate
3 percent, No. 3 3 percent, No. 5	Soft brown
3 percent, No. 3 1 percent, No. 7	Dark green
3 percent, No. 3 4 percent, No. 8	Mottled green and red
4 percent, No. 4	Dark blue-green
2 percent, No. 4 3 percent, No. 5	Cool green
2 percent, No. 4 1 percent, No. 7	Dirty blue-green
2 percent, No. 4 4 percent, No. 8	Dark green
5 percent, No. 5	Light yellow-green
3 percent, No. 5 1 percent, No. 7	Soft green
3 percent, No. 5 4 percent, No. 8	Mottled green and red
3 percent, No. 6	Deep blue
3 percent, No. 7	Blue
1 percent, No. 7 4 percent, No. 8	Light blue
1 percent, No. 7 4 percent, No. 9	Light blue
7 percent, No. 8	Red
4 percent, No. 8 4 percent, No. 9	Red-pink
7 percent, No. 9	Pink
6 percent, Seger Pink	Red-pink
5 percent, Tin oxide	White
10 percent, Tin oxide	Pure white
15 percent, Tin oxide	Immature
3 percent, No. 1	Soft light brown
3 percent, No. 11	Blue slate

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5 percent, No. 11	Blue slate
2 percent, Copper oxide	Light green
5 percent, Nickel oxide	Soft purple
1 percent, Cobalt oxide	Bright blue
2 percent, Manganese dioxide	Purple-pink
3 percent, Seger Pink	Purple-pink
4 percent, Antimony oxide	Dirty white
3 percent, Uranium oxide	Light yellow
6 percent, Uranium oxide	Yellow
3 percent, Ferric oxide	Yellow
2 percent, No. 7	Light blue
1 percent, No. 7	Very light blue
2 percent, No. 6	Dark blue
1 percent, No. 6	Light blue
1 percent, No. 10	Light purple-blue
2 percent, No. 10	Dark blue
2 percent, Chromic oxide	Yellowish green

Thus the purpose of the experiment had been accomplished. The desired combination of body, slip and glaze had been obtained, both in bright and mat effects and in a large number of colors. Below are summarized the body and slip batches, and the formulæ and batches for the bright white and mat white glazes. Any colors may be obtained in either glaze by using the proper stains as shown above.

Body mix:

Perrine's stoneware clay	79.5
Grog (12-45 mesh)	20.0
Barium carbonate	00.5
	100.0

Slip mix:

China clay (M. G. R. No. 1)	25.0
Tenn. ball clay, No. 1	6.0
Cornwall stone	45.0
German ball clay	6.0
Flint	20.0
Sodium carbonate	1.0
	103.0

BRIGHT WHITE GLAZE

$$\left.\begin{array}{l} K_2O\ 0.16 \\ CaO\ 0.44 \\ BaO\ 0.35 \\ ZnO\ 0.09 \end{array}\right\} : Al_2O_3\ 0.41 : SiO_2\ 3.7$$

Oxygen ratio 3.7

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BATCH WEIGHTS

Spar	113.12
Whiting	40.00
Barium carbonate	68.95
Zinc oxide	7.29
Florida clay	41.70
Tenn. ball clay	10.40
Flint	120.96
	402.42

MAT WHITE GLAZE

$$\left.\begin{array}{l} K_2O\ 0.16 \\ CaO\ 0.44 \\ BaO\ 0.35 \\ ZnO\ 0.05 \end{array}\right\} : Al_2O_3\ 0.37 : SiO_2\ 1.9$$

Oxygen ratio 1.8

BATCH WEIGHTS

Spar	113.12
Whiting	0.44
Barium carbonate	68.95
Zinc oxide	4.05
Florida clay	33.40
Tenn. ball clay	8.40
Flint	17.76
	289.68

This combination should be burned to cone 6 in a 50 hour burn, with slow cooling, to obtain the results tabulated above.

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ON THE BURNING OF ROUGH TEXTURE SHALE BRICK

BY WALTER A. HULL

The advent of the extensive use of rough texture face brick has been accompanied by a call for colors which were not in general use in earlier years. Formerly, most brick of colors other than red, were made from the various grades of plastic fire clay. In rough texture brick, a great variety of colors is produced from shale. Some of these colors are good by themselves; some are good when combined with other colors; and there are those which are not particularly good, either by themselves or in combinations. It is one of the problems of every builder, architect, dealer and brick maker to make the most of these colors. It is one of the face-brick maker's most important tasks to produce brick of desirable colors, to make the different colors in quantities suitable to the demand of his market without an excess of any of them, and to reproduce his colors at will kiln after kiln.

This matter is put up to the burner in various ways. He may be told to burn more dark brick, or more reds, or that there is a big market for this shade or that, "If we could only make them." Sometimes he has to burn brick for a large order that cannot be shipped wholly from stock, and he is expected to bring off a number of kilns very nearly like each other, and with as large a proportion of certain shades as possible. If he stops to analyze his duties and the range of his powers of production, he may put the matter down as follows:

1. Burning whole kilns of reds.
2. Burning and controlling modified reds.
3. Burning whole kilns that will make good run of kiln jobs as mingled shades.
4. To produce whole kilns of dark, or flashed brick that are reasonably uniform in shade.
5. To burn kilns that will turn out high yields of very dark brick.

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6. To produce a large proportion of red center and dark border brick.

If a burner can do these six things, is trying to improve and is a good man in other respects, he ought to be able to hold his job. If he, with the co-operation of his boss, can not do these six things with a fair degree of certainty, and understand how he does them, he has something yet to strive for and an incentive to keep on studying and improving.

The colors of the finished bricks from a given material are influenced by the hardness of the burn, by oxidizing and reducing conditions of the kiln atmosphere during the latter part of the burn, after the brick have attained a high temperature; and, last, but by no means least, by the conditions and manner of the cooling. All these influences, particularly in the use of downdraft kilns, are subject, in a measure, to the control of the burner; and the means of control seem worthy of discussion.

PREVENTION OF REDUCTION

This is of the utmost importance in the production of reds. In order to accomplish this prevention when necessary, and at the same time to burn economically, the burner must exercise continual vigilance and no little judgment and skill.

A reducing atmosphere in a kiln is easily detected, when the kiln is hot, by looking into the kiln chamber through a peep hole. If there is no reduction going on, one can see for some distance through the clear atmosphere of the kiln. If there is a straight peep hole clear through the kiln, he can see clear through to the wall on the other side. If, on the other hand, the atmosphere of the kiln is strongly reducing, it will look hazy inside, so that one can not see far into it. Flame may be visible, or it may not, and smoke may or may not be visible, coming from the stack. If the burner feels that he is running close to the danger line, and is in doubt as to which side of it he is on, it is well for him to draw a trial from his highest trial hole and see what he has been doing to it. He can tell by the color of the exposed surfaces, whether he is getting injurious reduction. Under certain conditions, particularly at finishing heats a very little "smoking" will

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spoil beyond recall the red color in the upper part of the kiln. At lower temperatures, it takes more reduction to do damage. While the bricks are still soft and porous, no care need be taken to avoid it. Just where the danger lines, both as to temperature and as to the dividing line between oxidation and reduction, are to be found, has to be determined by careful observation. If a burner is firing with a view to coal economy, he will get some reduction, now and then, when he means to avoid it. By noting the effect at such times, he will learn how far he dare go with his kiln, and with his material.

There are five rules which it is well to observe in preventing reduction in down-draft kilns. These apply particularly to kilns with inclined grates or with grateless furnaces:

1. Do not let fires burn down too low before recharging. Otherwise, the heavy charge required for filling up the furnace, has a tendency, once it gets to roasting, to throw a large volume of reducing gases into the kiln.

2. Do not go to the other extreme and fire too often. One of the surest ways to get reduction is to break down charges of coal that have just got to roasting well and are filled with combustible gases that are ready to escape with a rush, the moment the mass is broken up.

3. Do not burn with too low a draft. This should not be interpreted in an extreme sense, but a happy medium should be found.

4. Give some air inlet over the fires, when necessary.

5. Do not clean all fires in rapid succession. Skip every other one, the first time around and, if the kiln has a tendency to smoke, do not go too fast. This rule applies to firing as well as to cleaning fires. A burner can keep his kiln more nearly neutral without getting injurious reduction, if he will fire only every other furnace, as he goes around; and then, after these have burned clear for a time, go around the kiln again, firing the others. It is also good practice to leave fires tolerably open, over the fuel bed, while they are fresh and then partly close them after they have burned a little while.

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MAINTAINING REDUCING CONDITION

In producing colors other than red, one of the essential things is to have an effective period of reduction. To be effective, it must take place at a high temperature. It may be of a few minutes duration, or it may be maintained for a number of hours, according to the effect that is intended. In producing large quantities of brick of the darkest shades, the problem in burning is to keep up a strongly reducing condition in the kiln for a number of hours. The ease with which this can be done, depends, to a great extent, on the coal. A free burning coal, high in volatile content, is the most satisfactory, though results can be obtained with high carbon coals where necessary. The burn is carried on in the ordinary way until near the finish. Then, starting with clean fires, the draft is cut down, almost as low as it can be cut and still operate at all. Then the fires are closed tight, or very nearly so, breaking down the old fires and building up the new charge, in the case of doorless furnaces, until practically no air inlet remains. In a short time the kiln is in a strongly reducing condition, and this is evidenced by its being full of flame. Ordinarily, a considerable volume of black smoke issues from the stack, and usually the flue from the kiln to the stack, has a good stream of smoky flame passing through it. This flame gradually becomes less smoky and shorter, and the smoke from the stack becomes less, until, after a period of thirty minutes to an hour, the evidences of reduction, including the hazy appearance in the kiln chamber, have almost disappeared. This is taken as the indication that it is time to fire again. The fires are broken down, sometimes with the firing shovel and sometimes with a bar and then recharged as before. This sort of firing is kept up, with some variation, until the end of the reduction period.

If the reduction is to be of several hours duration, it is necessary to make allowance for the progress of the kiln during that period, in determining when to commence the reduction. In making this allowance, the burner usually judges, from previous experience, that the temperature in the top part of the kiln can be held nearly constant during the reduction period,

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while the bottom will progress a good deal faster during reduction than during clear firing. This is natural, as combustion is taking place extensively throughout the interior of the kiln and even down into the flues, while at the same time, the low draft tends to minimize the amount of cold air that filters in through the leaks in the wall and doors of the kiln. Therefore, the burner may judge correctly, that a kiln which would require say twelve more hours of clear firing to finish the bottom, will require only six hours of reducing firing to accomplish the same end. If it is his intention to reduce the whole kiln of brick strongly, he starts the reduction as soon as he judges that that sort of firing will finish the bottom, before it become ineffective by reason of the fires becoming too thick. If, on the other hand, the kiln is to be but slightly reduced, the reduction is made to take place in whatever portion of the finishing stage of the kiln, it has been found to have the desired effect.

During the long reducing periods, observations as to the progress of the "flashing" can be made by clearing the kiln for a short time and drawing trials. The kiln atmosphere is most easily cleared just before recharging, when the condition is becoming nearly neutral. An increased draft and slightly opened fires for a few minutes will then make trials and cones as well as the bricks in the setting, comparatively easy to see. Trials drawn in the early part of the reduction period are apt to show strong flashing in the upper part of the kiln, and little or none in the lower portion. The reduction is continued, for the darkest burns, until the bottom trials show a good flash and are hard enough to insure a good bottom.

In burning shales which have a tendency to go out of shape easily in burning, and with which it is necessary to exercise extraordinary care in order to get a good bottom without overburning the kiln, the clearing of the kiln atmosphere at intervals enables the burner to see how the setting is standing up. He can judge not only by what he can see in the peep holes but also by looking down through the crown hole. Ordinarily, there is not much tendency for the brick to lean and go out of shape during the reduction, unless either too much draft is carried, or

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the brick had commenced to lean before the reduction was started. In any case all the means of judging the condition of the kiln, including, pyrometer readings, taking of settle, observation of cones and trials and looking over the setting itself to see how it is standing, are available during the reduction period. With a sensitive shale, careful observations are necessary in either an oxidizing or a reducing finish. There is somewhat less trouble likely to be experienced in getting a good bottom in the flashed kilns, than in red burns, for reasons previously mentioned.

There is a limit to the length of time during which the reduction can be effectively maintained, in ordinary practice, as the fuel bed has a tendency to thicken and finally becomes too thick to admit of keeping up the temperature. This is especially true in burning sensitive shales. The draft is kept very low in order that the tight and somewhat heavy firing shall not raise the temperature unduly, and the fuel accumulates because it does not burn out rapidly. This can be controlled to some extent by cutting down the frequency of the firing and the amount of the charge, at the expense of the excess of reducing constituents in the kiln atmosphere. Furthermore, it is possible to keep up strongly reducing conditions with comparative light and infrequent firing, by the use of coal tar or some other liquid fuel. A good method of introducing such a fuel is to allow it to trickle into the kiln in a thin stream from a container placed over an opening at the top of the kiln crown. A powder can with a nail hole in the bottom, serves very well. It is a good precaution to have a wire, extending through the orifice and reaching over the top of the can, to enable the operator to keep the opening free, as there is a tendency for it to become clogged. The use of tar is effective in assisting the coal fires in keeping an excess of reducing gases in the kiln, and its use may be justifiable, particularly with short flame coals. Half a barrel of tar will serve over a period of several hours. However, it is some trouble to use it, and in some cases a serious dicoloration of a considerable number of the brick is attributable to it. Whether it is desirable to use it, under given conditions, can best be de-

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termined by experiment. It offers a possible help to the burner, especially where it is necessary to use short flame coal.

According to the writer's experience, from four to six hours of strong reduction is usually sufficient time to get a good flash to the bottom, if a kiln is behaving normally. On the other hand, it has been found possible, where tar is used, to prolong the reduction period up to twelve hours and longer. So long as the fires can be kept in such condition that they are effective, that is to say, capable of maintaining the temperature of the kiln, the bottom will continue to make progress, and a long reduction period tends to make an even kiln, in point of hardness of burn.

COOLING

When a dark, or "flashed" burn is finished, top, middle and bottom trials are all nearly black, and their predominant color is green or bluish green. If the brick could be taken out of the kiln, at that stage, and quickly chilled, as is done with the trials, the brick would be as dark as these finishing trials. In practice, the reverse is true. The cooling, in ordinary practice, takes place under more or less strongly oxidizing conditions. The tendency is for oxidation to take place rapidly while the brick are still at high temperatures and at a gradually lessening rate during the progress of the cooling, down almost to atmospheric temperature. This reoxidation, following the reduction, brings the color back, through various combinations, toward the red, and the result is a kiln of brick of a variety of colors in all of which red, yellow, blue and green are intimately intermingled in various proportions. The colors of the finished product are dependent to so great an extent upon the chemical changes which take place during the cooling, that this process lays special claim to the burner's study. The problems of the control of reoxidation are fully as important as those of the reduction period. If there were no reoxidation, strongly reduced kilns would turn out, as is indicated above, nearly black brick in which the colors would be a combination of green and blue, with the green predominating. If it is desired to keep the brick as dark as possible, there are two, very different, lines of attack from which to choose. Either the kiln must be cooled in a non-oxidizing atmosphere, or

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the cooling must be accomplished in as short a time as possible. So far as the writer is informed the only commercial attempts to cool rough texture brick by the former method have been along the line of sealing the kiln as tightly as possible at the conclusion of the burn, while the kiln atmosphere was still reducing. The writer is not sufficiently familiar with the results obtained in this way to make record of them here. His experience in commercial practice has been entirely with cooling in an oxidizing atmosphere. Beautiful lines of shades are produced by this method; and it has two distinct advantages over the former method. In the first place, it renders a portion or all of the waste heat available for drying. In the second place, it is a quick method and admits of getting the maximum output from the kilns.

In cooling under oxidizing conditions, the colors are influenced, as would be expected, by the rate at which the cooling takes place, the color changes taking place more rapidly and being more pronounced in the early part of the cooling, while the temperature is the highest. Very marked changes are made during the first few minutes of oxidation, and most of the reoxidation that occurs is accomplished within the first few hours of the cooling. On the other hand, important changes in the colors continue to take place even after the temperature of the bricks has fallen below that of redness, so that, while the rate of cooling exerts by far the greatest influence at the highest temperatures, its effect in the latter stages should not be wholly overlooked.

It is well to recognize, in the beginning, the fact that a brick, located somewhere in the midst of the contents of a kiln and surrounded and influenced by say seventy-five thousand other bricks, is not likely to be cooled very quickly, no matter what is done to the kiln. When the burner starts to practice rapid cooling, he may be surprised to find out that he can not control the rate as well as he supposed he could. Cooling on the fan without opening up doors and crown hole is too slow. If the kiln is put on the fan, and all the movable parts of the kiln shell, including wickets and crown hole covers are removed,

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there will be a spectacular show of escaping heat; and the kiln will cool at a comparatively rapid rate. Even so, practically all of the brick in the kiln will remain incandescent for hours, and, as is readily observed, both during the cooling, and when the kiln is being emptied, the great interior portion of the setting will cool much more slowly than the outer portion, nearest the wall and crown, where the brick are more exposed to the cold air which enters the kiln. If the kiln is given a back draft, by admitting air through the underground flues, and sufficient exits are provided in the crown and upper part of the doors to correspond to this inlet, the cooling will be more positively directed and the kiln will cool more uniformly. In any case, there will be considerable reoxidation in practically all the brick. However, these methods do produce comparatively dark shades of flashed brick, and they may be capable of development and improvement along practical lines. The rate of cooling depends to some extent on the construction of the kiln. Large doors, large crown openings and ample flue capacity have an influence, and types of furnaces which can be made to afford large air openings as soon as the burn is completed, are of assistance. Quenching the fire with water is practiced and at least one manufacturer is trying a kiln with four doors, all of which are opened at once, by tearing down the wickets, as soon as the burn is finished.

These methods of cooling have little apparent effect on the strength of the brick or on the kilns. They are, however, wasteful of the heat, as a large portion of it escapes even if the kiln is put on the fan as soon as the cooling is commenced. If wholly satisfactory results are to be obtained in producing the very dark shades, it would seem necessary to build special kilns for the purpose. Small kilns, with large waste heat connections and kiln flues should give the desired results in color without a great sacrifice in economy. The number of such kilns built on a yard could be governed by the quantities of very dark brick, that it was considered desirable to produce.

While the means of control at the burner's command are limited and imperfect in their operation, yet it is worth the most

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careful study, to be able to use them to the best advantage, and to facilitate such study, some crude directions may be given.

BURNING KILNS OF REDS

This, in a way, is the simplest task of all. All one has to do, is to burn a good kiln of brick without producing a reducing atmosphere in the kiln, at any time after the bricks have commenced to harden. In other words, keep the kiln clear all the time, during the latter part of the burn, after the pore spaces of the bricks have commenced to close up. If this is done, with a red burning material the brighest, clearest reds which the material is capable of producing, in that kind of a kiln, should be produced. This is comparatively easy in continuous kilns, because, in ordinary practice, there is always a large air excess in the burning zone. With up-draft kilns, so far as the writer's experience goes, there is not likely to be any long continued reduction, if any at all, and the natural tendency is to burn clear reds. On the other hand, reds produced in up-draft kilns are not necessarily the same, as those burned from the same material in down-draft kilns. A case in point is one where shale brick were burned in both up and down-draft kilns on the same yard. Good reds, from a common brick standpoint, were regularly burned in the up-draft kilns. They would even pass for face brick reds, yet they did not compare well with brick made from the same shale and burned in the down-draft kilns, nor would they shade up with them.

BURNING MODIFIED REDS

Almost any burner will get some flashed reds in spite of himself and call them off-shades. But some of them may be good shades, and it is well to reproduce them on purpose. They can be burned, in kilns of brick set on the flat, so that the faces are exposed, by giving the kiln a period of reduction, or a series of such periods, near the finish of the burn, following it with a period of oxidation before the cooling is commenced. The resulting colors are affected by at least four influences, all of which are subject to the burner's direction:

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1. The stage of the burn at which the reduction takes place.
2. The length of time during which the reduction continues.
3. The time during which the kiln is allowed to burn clear after the reduction.
4. The cooling.

Good flashed reds, including dark and light browns with an undertone of red, can be produced by giving the kiln one or more periods of moderately strong reduction, just before the finish of the burn, followed by the oxidation incident to letting the fires burn low and then cooling moderately fast. From fifteen to thirty minutes of reduction give considerable flash. Finishing the kiln on a low draft, and firing so that there is a short period of reduction, whi'e fires are fresh, is a method worth trying out, and there are other practical variations.

The kiln can be cooled, on the fan alone, or on the fan with openings made at wickets or crown hole, either in the early part of the cooling or after any number of hours.

In order to attain proficiency in producing good shades and in reproducing them, it is necessary to keep records of both cooling and burning. These should include the firing record, or a statement of just what was done, and how, and at what time. At the critical stages. especially just before and after reduction, trials should be taken, and these should be tagged and kept for reference. Time-temperature records of cooling would be helpful and should be kept, if a pyrometer is available. Careful records are of more importance in the production of the more delicate, only moderately flashed colors than in either the reds or the very dark brick. This field is most promising and attractive and has not received general attention.

BURNING WHOLE KILNS THAT WILL MAKE GOOD RUN OF KILN FOR MINGLED SHADES

There are three distinct types of setting that can be used for this purpose, and each type gives its own sort of run of kiln with a given burn:

1. Setting all brick on edge, either faced or not.
2. Setting all brick on the flat, with all faces exposed.

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3. Setting the brick in the upper portion of the kiln on the flat and the lower courses on edge, faced.

Setting All on Edge. With shales that do not require sanding to prevent sticking in the kiln, this method of setting gives good results. If the reduction is not carried too far, that is, kept up strongly for too long a time, the upper courses will be well flashed, and good dark shades over the entire face of the brick; the brick lower in the kiln will have red centers and flashed borders and the bricks in the bottom will be good reds, though perhaps modified, to some extent, especially at the borders of the faces. This sort of a kiln makes a good effect in a run of kiln job. If the kiln is reduced for a longer period, the proportion of all dark faces will naturally be greater; there will be a good proportion of faces with red centers and dark borders, and a small proportion, or perhaps none at all, of all red faces. The latter sort of kiln gives a good mingled shades output and of course makes a darker job than the former sort.

With brick which require sanding, this is not such good setting practice, as the sand will stick in the rough faces to some extent and detract from their appearance. Brick in which the texture has high relief, or in other words, brick of very rough texture, do not retain the original texture when set in this way, as the breakage of the high points and ridges as well as the flattening down under pressure, at high temperatures, leaves them comparatively smooth after burning.

Setting all Brick on the Flat, with Faces Exposed. It is evident, that a kiln set in this way will have practically no faces with red centers and dark borders. Unless the period, or periods, of reduction be short, there will be few, if any, good clear reds in the burn.

One objection to this method of setting is that there is more tendency for breakage in rough texture brick set on the flat than set on edge, and particularly in the lower part of the kiln. Taking everything into consideration, this method of setting is hardly to be recommended, except for brick whose texture would be impaired by setting on edge.

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Setting the Lower Part of the Kiln on Edge and the Upper Part on the Flat. By this method of setting, a large proportion of all-flashed, dark faces can be obtained and a relatively small proportion of red centers and all reds. It can be used, at least in some cases, with brick that have a tendency to stick unless sanded, because there is less of this tendency in the lower part of the kiln, where the burn is not so hard. It has the advantage of minimizing the breakage in the lower part of the kiln, and it can give a good combination of run of kiln colors.

With many of these methods of setting, combinations of colors made by the run of kiln, depend on the burning and cooling factors indicated under modified reds. If the period of reduction is short and is followed by oxidation at high temperatures, the range should be from dark browns to reds, with intermediate shades of reddish browns and brownish reds, or of red centers and flashed borders, according to the method of setting. Longer reduction and less oxidation at high temperature following it, tend to darken the average of the kiln. The darkest kilns are to be produced by a long period of strong reduction, followed by rapid cooling. Forced cooling is commenced while reduction is still going on, so as to admit of as little oxidation at high temperatures as possible.

BURNING WHOLE KILNS OF DARK BRICK, REASONABLY UNIFORM

The greatest uniformity is obtained with brick set on the flat. A long period of strong reduction is followed immediately by rapid up-draft cooling, which was referred to in the discussion of cooling. With ordinary down-draft kilns, of moderate or large size, the cold air entering through the flues in the bottom of the kiln and passing up through the setting by natural draft, cools the kiln more nearly uniformly, than when admitted otherwise, whether allowed to escape naturally, through openings provided, or drawn out by stack or fan. With this sort of cooling, the greater part of the darkest brick should be in the very bottom courses, and a very large part of the kiln should be nearly uniform.

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OBTAINING HIGH YIELDS OF VERY DARK BRICK

The kiln is reduced strongly for several hours, at the finish of the burn, and a strong flash secured throughout the kiln. When this is accomplished, and the burning is to be stopped, preparations are made for starting cooling as suddenly as possible. Beginning at a time when the kiln atmosphere is in a reducing condition, everything that can be opened to let out hot air and let in cold is opened. This includes furnaces, doors, crown holes and stack flue. As soon as danger from sulphur can be eliminated by quenching fires, the fan is put on. Special care is exercised that this forced cooling is started during active reduction, and that not even a few minutes of neutral or oxidizing burning shall take place immediately preceding the cooling.

The brick in the top and around the outer portion of the kiln, being cooled most rapidly, by air entering at the sides, through doors and furnaces, are darkest. The brick in the central part of the kiln are relatively protected and have more of the red and yellow in their color. With some materials, the colors obtained in the central portion of the kiln are less desirable, than those resulting from cooling up-draft, with the air entering from the bottom flues.

BURNING FOR A LARGE PROPORTION OF RED CENTER AND DARK BORDER BRICK

In the nature of the case, brick are set on edge, faced, for this kind of a burn. Flashing should not be commenced until the kiln is ready to finish and should not be kept up too long. Special trials may be used in the first burns to determine the extent to which the flashing penetrates between the faces, and to judge when the reduction has been kept up long enough. The method of cooling should be governed by the sort of kiln that is desired, with reference to the flashed borders.

TRAINING BURNERS

In the writer's judgment, more than half of the problem of accomplishing good burning consists of training burners for their work. If a man is intelligent enough to make a good

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burner, he is intelligent enough to make observations in cause and effect. Very likely he does not know how to go about making these observations systematically. He may not know what to look for, and when and where to find it. He may not be able, without assistance, to analyze his observations and draw correct conclusions; but if one will study these things with him, repeatedly, patiently and sympathetically, he will, if he is the right sort of man for his job, gradually come to take an interest in the things that he should make a study of, and to take a pride and satisfaction in what he is able to accomplish. Then he will become a better burner, because of his improved powers of observation and his better understanding of his problems, and also on account of the chastening effect of realizing that there are things that he ought to know and would like to know, about his own work, which he has not yet been able to learn.

It is not necessary to confuse burners with technical terms. There are plenty of ordinary words that will answer all purposes. It matters little if men call a reducing atmosphere, a flame, or if they say a trial or brick is smoked, when it has been flashed. These simple, non-technical words can be used intelligently, and the main thing is to take pains always to apply the same word to the same thing, so that there is no question as to its meaning, so far as the matter in hand is concerned and less chance for talking at cross purposes. If the men are encouraged in it, they will have many suggestions to make and many theories to advance. All these should be taken seriously, whether reasonable or not. Sympathy and appreciation travel a long distance in the making of a man's attitude.

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DATA ON THE EFFECT OF VARYING COMPRESSION LOADS APPLIED TO CLAY IN THE PLASTIC CONDITION

BY CULLEN W. PARMELEE

As the result of experiments by Dr. Seger,[1] he concluded that, "The increase of density caused by repressing (clay) in the leather hard condition is rather small compared with the wet molded clay, as is to be expected for theoretical reasons." This opinion is not shared, apparently, by more recent contributors to technical literature as shown in the following references: In the *Report of the New Jersey Geological Survey on the Clay Industry,* Volume VI, page 260, we find the statement that, "Repressing increases the density (of brick) and therefore decreases the absorption." On page 459 of Volume XI of *Missouri Geological Survey on Clay Deposits* we read, "Repressed brick are somewhat denser and usually slightly stronger than unrepressed." In Volume XIV of the *Geological Survey of Iowa,* page 206, we read that the purpose of repressing is to produce a denser and stronger brick. On page 207, it is stated that, "Where the brick fits the mold perfectly tight, and therefore no flow can occur when pressure is applied, it is seen that practically no change in structure can be brought about only a change in compactness of the brick."

In view of the divergent opinions held by Seger and others cited, it seemed worth while to give a little time to the study of the matter. Seger's observations were limited to a half dozen experiments, at least in so far as has been published, and the repressing was done by tapping the clay in the mold with a hammer. We have undertaken to record the results obtained by applying loads of varying magnitudes which could be exactly adjusted and measured. The clay trials were in the plastic condition, as the bar would issue from an auger machine ready to be cut into brick and repressed.

The clay used was of a buff burning sort, having a good

[1] *The Collected Writings of Herman Seger,* Vol. I, 400.

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plasticity and remaining still absorbent when burned to cone 11. After pulverizing to a coarse powder, adding a suitable quantity of water and thoroughly wedging the mass until uniformly plastic, it was stored in a damp place over night to allow the mass to become of a uniform condition. From the mass, trial pieces were prepared having nearly the same diameter as the die which was used and a height of about 2.5 c.m.

The trial pieces were now ready for compression, and for this purpose there was at hand a die consisting of an iron block bored through with a cylindrical hole 15 c.m. long and 5.3 c.m. in diameter. Fitting this hole snugly was a piston longer than the bore of the die and in addition, it was found necessary to provide a tightly fitting plug for the bottom of the die. Between the bottom plug and the piston were placed the trial pieces. The die with its load was placed upon the bed plate of a 100,000 pound Riehle compression machine. When the pressure exceeded 10,000 pounds, water began to appear about the plug at the base of the die, and at 15,000 pounds clay exuded.

After drying, the trial pieces were burned at cone 6½ in a coal-fired laboratory kiln, the duration of the burn being approximately twenty hours.

The drying shrinkages of the pieces did not appear to be affected in any way by the compression, and the same was true of the burning shrinkages.

The measure of the change of density, i. e., compactness, is the change in the porosities of the trial pieces as affected by the varying compression loads, to which they had been subjected. We have three porosities to consider, namely, that of the open pores or "apparent porosity;" that due to the pores which are sealed, and finally the total porosity which is the sum of the other two. The "apparent porosity" was calculated according to the following formula:

$$\frac{\text{Soaked weight—dry weight}}{\text{Soaked weight—immersed weight}} \times 100 = \left\{\begin{array}{l}\text{percent open pores}\\ \text{or apparent porosity.}\end{array}\right.$$

The volume of the whole piece less the volume of the solid equals total pore volume. Total pore volume less volume of open pores

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equals volume of sealed pores. The volume of the solid was determined from the true specific gravity which, in turn, was obtained from a portion of the sample powdered to pass a 100 mesh sieve. A good laboratory balance was used for all the weighings, and the powder was boiled in a pycnometer under reduced pressure. The pore volumes in the accompanying table are calculated in terms of the volumes of the solid.

TABLE I

POUNDS PRESSURE ON THE WHOLE SURFACE	MOISTURE CONTENT PERCENT	APPARENT POROSITY[1] PERCENT	TOTAL POROSITY[2] PERCENT	OPEN PORES[2] PERCENT	SEALED PORES[2] PERCENT
Molded by hand	18.40	20.47	33.35	27.29	6.06
	18.20	19.54	32.79	25.95	6.84
	18.20	19.88	32.32	26.31	6.01
2,000	17.10	19.86	32.06	26.23	5.83
2,000	17.00	20.67	32.94	27.49	5.45
4,000	20.20	20.94	31.75	27.60	4.15
4,000	17.30	20.88	33.15	27.88	5.27
6,000	16.90	21.24	31.76	27.99	3.77
6,000	17.40	20.58	31.41	27.05	4.37
8,000	17.00	20.73	32.10	27.38	4.72
8,000	17.40	20.29	30.96	26.57	4.39
10,000	16.50	20.28	32.27	26.83	5.44
10,000	16.00	20.61	28.71	26.53	2.18
12,000	16.90	20.84	29.90	27.08	2.82
12,000	16.90	20.45	32.05	27.00	5.05
15,000	17.20	20.46	31.40	26.82	4.85
15,000	17.70	20.92	30.24	28.02	2.22
20,000	16.80	20.76	31.60	27.32	4.28
20,000	17.50	21.79	30.05	28.30	1.75
30,000	16.40	19.85	33.29	26.53	6.76
30,000	16.90	20.71	32.13	27.37	4.76
40,000	15.20	20.07	30.04	26.10	3.94
50,000	15.60	21.44	33.30	28.58	4.82

[1] Calculated in terms of whole volume.
[2] Calculated in terms of volume of the solid.

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From the data thus gathered, it is quite evident that compression of this clay in a plastic state in a die has little if any effect upon the density, i. e., compactness of the material, and certainly there is no relationship between the magnitude of the compression load and the porosities. The variations in the volumes of the pores is probably attributable entirely to lack of perfect homogeneity in preparing the plastic mass. These results are in accord with Seger's views, and as he says, may be expected from theoretical considerations. That is to say, the water in the mass is practically incompressible, and also we may believe the same is true of the particles constituting the clay mass. The practical application of this investigation is the important point, that in the repressing of brick, any pressure used in excess of that actually required to cause the clay mass to fill the die, is wasted energy. The repressing of brick is useful in enabling us to make brick with smooth faces and sharp edges, and for the imprinting of trade names or other devices. In addition to these, the Committee on Technical Investigation of the National Brick Manufacturers' Association[2] some years ago reported that repressing may be used to "cause a radical breaking up of an auger machine structure and the production of a new and characteristic structure due to repressing." Possibly repressing, by creating a new structure, may give a greater density due to the removal of air blebs, or better welding together of laminations, yet this apparent increase in compactness, if any, is not properly attributable to a compression of the clay mass. A better remedy in such a case would be the correction of errors in auger or die construction. In this connection it is well to note the statement made by Bleininger[3] that repressing has the tendency to lower the crushing strength which is in accord with Bourry[4] who says "under the influence of pressure, the molecules of the body are put out of place and to a certain extent pressed together; but as the plasticity of them is very weak, they blend very badly together and cracks are left in the goods, as well as smooth parts, which lessen the resistance to breaking."

[2] *Iowa Geol. Survey*, Vol. XIV, 209.
[3] *Trans. Amer. Cer. Soc.*, Vol. XII, 582.
[4] *Treatise on the Ceramic Industries*, First Ed., Rex, p. 475.

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DISCUSSION

Mr. Lovejoy: I take it, Prof. Parmelee, that the conclusion you have reached, is that there is neither advantage nor disadvantage in repressing.

Prof. Parmelee: That seems to be the case, in so far as the porosity of the piece is concerned. There is possibly an advantage in repressing, as thereby the structure of the brick may be altered. This has been noted by others, especially by the committee which some years ago undertook to study the effect of repressing upon the structure of paving brick. There may also be an advantage, in so far as the repressing affects the form and appearance of the brick. The density, however, seems to be unaffected by repressing.

Mr. Lovejoy: I wish to bring out that point. The general opinion is that it is an advantage to repress brick, but in ordinary brick repressing there is no compression, the clay mass is simply spread out to fill the mold, and lamination planes are frequently opened by the movement.

Prof. Parmelee: The statement has appeared in print that a pressure as great as forty-five thousand pounds may be applied by a repress to a brick. According to the results of our investigation, the application of a pressore of such magnitude to a body in a plastic condition is largely a waste of energy.

Mr. Gurner: Mr. Lovejoy, you stated that there is no decided advantage in represing brick. Did I understand you to make that statement?

Mr. Lovejoy: We believe there is no advantage but on the contrary a disadvantage.

Mr. Gurner: Was it not the opinion formerly that it took out the air bubbles which did not reappear.

Mr. Lovejoy: I think that the purpose is to increase the density and shape up the product.

Mr. Gurner: The reason that I asked was, that in some kinds of tile they repress to get rid of air. I do not know whether in the test that Mr. Parmelee conducted any attention was paid that. I should like to know whether it was or not.

Prof. Parmelee: We were studying a plastic body contain-

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ing 16 to 17 percent of water, while you probably are referring to a dust body.

Mr. Patterson: Professor Parmelee's experiments to determine the effect of pressure upon the density of fire clay or shale products are of great interest to the manufacturers of vitrified paving blocks, as bearing upon the question of repressing the paving blocks in order to improve their quality. There are those who contend that the repressing is not only of no advantage but a positive injury to the blocks; that the repressing to some extent destroys the original bond, and that the pressure of the repress is usually less than the pressure of the brick machine; that the column as it comes from the brick machine has greater density than is possessed by the repressed block as it comes from the repress. Some manufacturers contend that the wire-cut block, not repressed, will stand a better rattler test than the same block repressed.

We can readily see from the results obtained from Prof. Parmelee that after a certain amount of pressure has been applied, and a dense body obtained, that additional pressure would produce little or no change in density. We are unable to state from our experience whether there is any difference in density of the clay bar as it comes from our brick machine, and the repressed blocks made from the same column as they are taken from the repress.

We have, however, made a number of experiments in order to determine the abrasive qualities of these two products of the paving block manufacturer, viz., the wire-cut block and the repressed block. We speak for our own material only. We use a fire clay which burns to a light buff. We entered the paving brick business in order to make money. We are desirous of making the wire-cut block, as we could dispense with the repressing and thereby lower the cost of production. From the column of clay as it proceeded from the brick machine, a number of brick were cut by the wire cutter. Some of these were placed in the dry car without being repressed, and others were repressed and placed on the same dry car. The two kinds of blocks were carefully kept together in the drying tunnels, in the kiln, and taken

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from the kiln to the rattler room, where they were carefully tested for abrasion in the standard rattler, as devised by Orton and Blair. Spherical shot were used, weighing three hundred pounds to a charge, and the rattler revolved 1800 revolutions for one hour, the time of rattling the blocks for one test. We made a number of such tests at different times, and up to this time we find the repressed block made from our material stands a better rattler test than the wire-cut block of the same material. Wire-cut blocks have sharp edges, and repressed blocks have curved edges. No doubt the curves would save the repressed blocks in the rattler, and there would be a greater loss in the rattler in the case of the wire-cut blocks, by reason of the sharp edges. Whether the sharp edges in the one case and the rounded edges in the other made the difference in the percentage of loss in the rattler we are unable to say; but in order to keep ourselves from going into bankruptcy, we found it necessary to continue making repressed blocks.

Mr. Doe: We made two tests to determine the effect of repression on absorption. In the brick from the rattler, there seemed to be no difference in absorption between the repressed and the wire-cut, but in the brick as it came from the kiln, we found that the repressed absorbed a little less than the wire-cut.

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THE EFFECT OF THE ADDITION OF LIME AND SILICA TO A SHALE[1]

BY PAUL TEETOR

The data presented in this paper is the result of a piece of work which was carried on to develop a short method, suited to the needs of the ceramic laboratory of the Kansas State Geological Survey, of determining whether or not some of the large deposits of shales and clays of an inferior nature in Kansas can be sufficiently improved to warrant their use for the manufacture of clay products such as paving brick.

The two shales used in this experiment, No. 110 and No. 154, are being utilized for the manufacture of paving block. Shale No. 110 is being used commercially just as it occurs in the shale bank and produces a good grade of paving block. Its plasticity is a little lower than that of the average paving brick shale, and when burned to produce a brick of minimum rattler loss, it still has a rather high porosity, a porosity of nine percent. The rattler losses of the product made from this shale vary quite a bit, and it was thought that this experiment might reveal a mixture which would produce more uniform rattler losses.

In order to study the effect of adding lime and silica to shale No. 110 the following mixtures were used:

Shale alone
Shale plus 1 percent calcium carbonate
Shale plus 2 percent calcium carbonate
Shale plus 3 percent calcium carbonate
Shale plus 1 percent flint
Shale plus 3 percent flint
Shale plus 5 percent flint

These mixtures were thoroughly mixed in the dry state, and tempered with water in the wet pan. The wet clay was then batted out to a slab of uniform thickness between two guides, and this slab cut into test pieces 3½ inches in diameter and 1⅝ inches thick. These test pieces were dried and burned to cone 4

[1] By permission of the Director of the State Geological Survey of Kansas.

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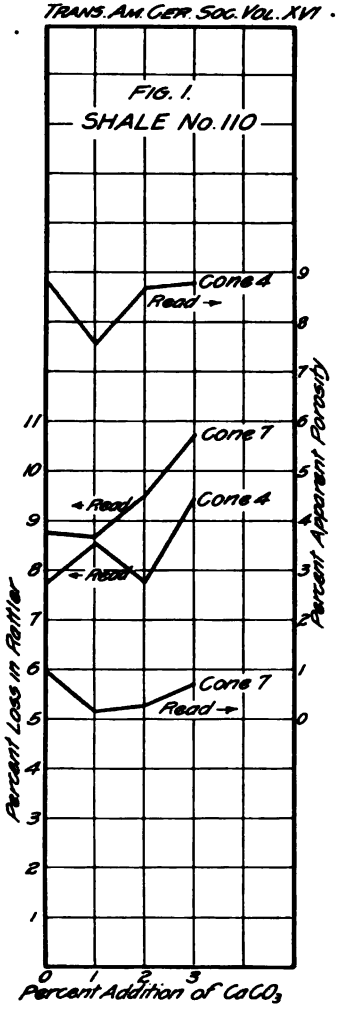

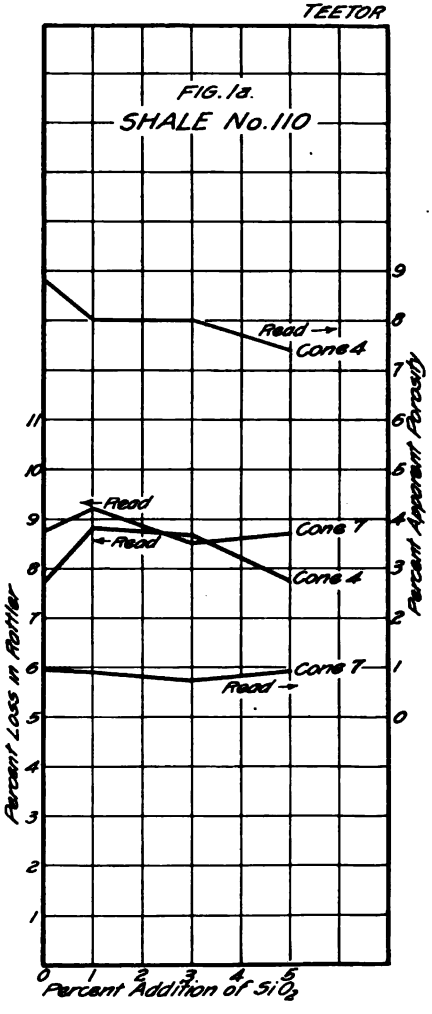

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down in 70 hours. After shutting off the gas, the kiln was sealed and allowed to cool; the time required for cooling was 3½ days.

A portion of these test pieces were reserved for porosity and specific gravity determinations, and the remainder were used for the rattler test.

After a little preliminary experimenting with the various laboratory rattlers available, the following was decided upon: To use the new rattler as specified by the *N. B. M. A.*, the abrasive charge was 225 pounds of the small shot (1⅞ in. in diameter). The charge of test pieces was ten in number with a total weight of approximately 8¼ pounds, number of revolutions per minute of rattler was 30 and the duration of the test, 30 minutes.

In order to determine the effect of over-firing on these mixtures, another set of test pieces were burned to cone 7 down. The same precautions were taken during cooling as in the cone 4 burn and the rattler test made as before. The numerical data obtained from the rattler tests is recorded in table No. 1 and is shown graphically in Fig. 1.

TABLE I—SHALE No. 110

	CONE 4 BURN		CONE 7 BURN	
	RATTLER LOSS PERCENT	POROSITY PERCENT	RATTLER LOSS PERCENT	POROSITY PERCENT
Shale alone	7.71	8.84	8.72	0.99
Shale+1 percent $CaCO_3$	8.55	7.59	8.68	0.16
Shale+2 percent $CaCO_3$	7.75	8.71	9.52	0.24
Shale+3 percent $CaCO_3$	9.52	8.81	10.77	0.70
Shale+1 percent flint	8.88	8.04	9.23	0.94
Shale+3 percent flint	8.70	8.06	8.58	0.75
Shale+5 percent flint	7.76	7.42	8.89	0.93

A careful inspection of the curves shown in Fig. 1 seems to indicate that the addition of calcium carbonate to this shale does not decrease the porosity. The toughness of the burned product

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is reduced by the addition of calcium carbonate as indicated by the increase in the rattler test.

The addition of silica to this shale has no effect upon the toughness as measured by the rattler test.

Composition of shale No. 110:

SiO_2	67.66
Al_2O_3	14.33
Fe_2O_3	7.27
CaO	0.70
MgO	1.21
K_2O	0.76
Na_2O	1.84
Ignition	5.25
Moisture	1.15

The porosity-temperature curve of shale No. 110 is shown in Fig. 2. This shale has a drying shrinkage of 4.95 percent and a burning shrinkage of 5.5 percent at cone 3. The porosity of commercial paving bricks made from this shale have been found to vary between 9 and 15 percent.

The other shale, No. 154, used in this experiment is of an entirely different nature. It has greater plasticity, with a slight tendency to warp, its drying shrinkage is 5.7 percent and its burning shrinkage is 8.71 percent at cone 2. The porosity-temperature curve as shown in Fig. 2 shows that the porosity decreases very rapidly between cone 08 and 02, then remains fairly constant until cone 5, when it begins to increase again.

The true specific gravity of this shale when burned at different temperatures is shown in Fig. 2. The specific gravity was determined by the pycnometer method.

The experimental work with shale No. 154 was restricted to the addition of silica, which was added in two forms, the coarse sand and the finely ground potters flint. The mixtures used were as follows:

Shale alone
Shale plus 2 percent sand
Shale plus 2 percent flint

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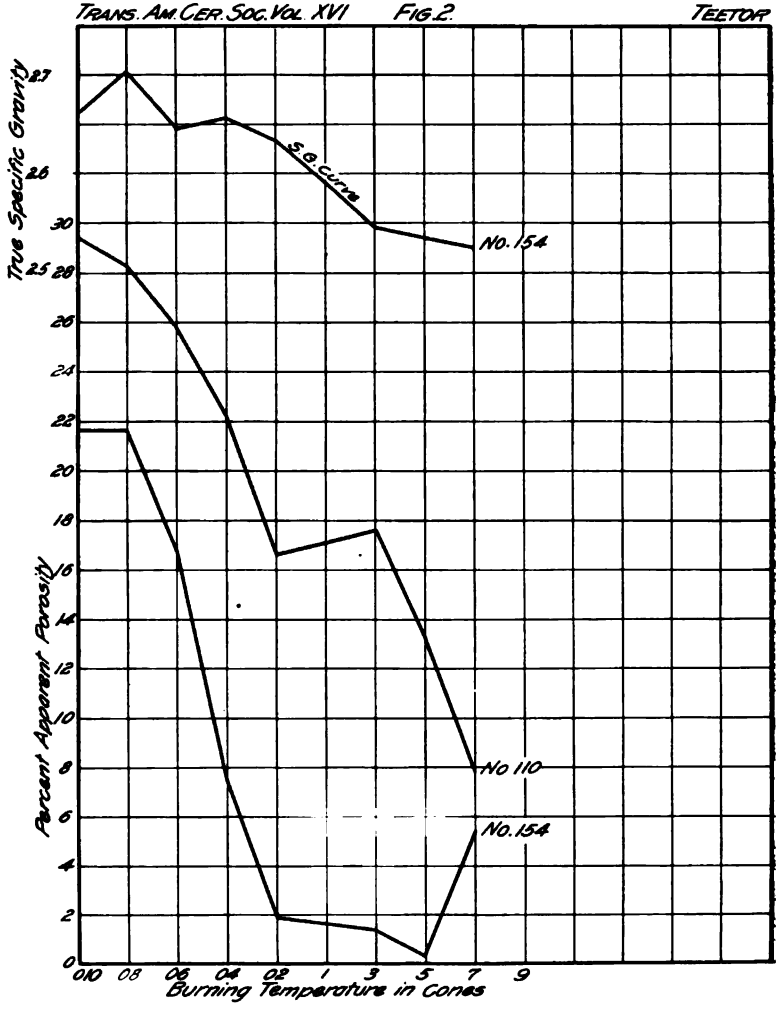

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Shale plus 7 percent sand
Shale plus 7 percent flint
Shale plus 14 percent sand
Shale plus 14 percent flint

Test pieces for this lot were prepared just the same as for shale 110. The first lot was burned to cone 2, and the same precautions were taken during cooling as before. The rate of raising the temperature of the kiln after oxidation was completed was 20°C. per hour.

A second lot of test pieces from these mixtures were burned to cone 7 down, to determine the effect of over-firing.

TABLE II—SHALE No. 154

	CONE 2 BURN		CONE 7 BURN	
	RATTLER LOSS PERCENT	POROSITY PERCENT	RATTLER LOSS PERCENT	POROSITY PERCENT
Shale	10.45	0.29	13.32	0.30
Shale+ 2 percent sand	11.08	0.28	12.50	1.38
Shale+ 2 percent flint	10.42	0.55	14.50	0.06
Shale+ 7 percent sand	8.52	1.60	15.67	1.30
Shale+ 7 percent flint	8.16	0.47	9.63	0.03
Shale+14 percent sand	8.51	3.13	15.47	1.09
Shale+14 percent flint	7.26	1.17	9.27	0.06

The chemical analysis of the sample of shale used in this experiment could not be completed in time for incorporation in this paper. The shale bank is made up of two layers, and the composition of these two layers as determined in the chemical laboratories of the University of Kansas is as follows:

	UPPER LAYER	LOWER LAYER
SiO_2	61.02	51.57
Al_2O_3	15.38	14.64
Fe_2O_3	9.12	14.84
MgO	1.34	1.44
CaO	0.48	0.49
K_2O+Na_2O	3.57	4.96
Ignition	6.69	6.43
Moisture	2.40	5.61

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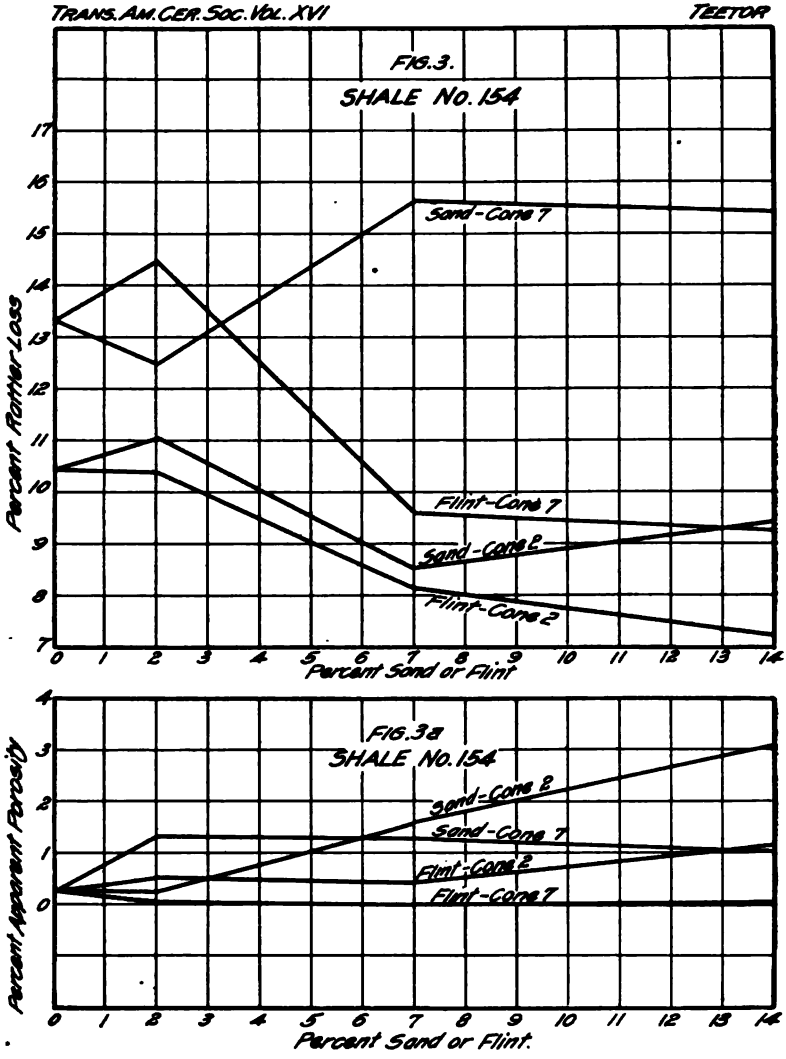

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An examination of the curves shown in Fig. 3 shows that the addition of silica to this shale is beneficial and advisable, in as much as it produces a material decrease in the rattler losses. This fact is also born out in practice; bricks made from the shale itself have a rattler loss of 22 to 23 percent, while the sand-shale mixture rattles in the neighborhood of 18 percent. It also appears that for this shale the fineness of grain of the added silica does not play a very important part in case of a normal burn, although in this case the fine grained silica produces slightly lower rattler losses. In the case of an overburn the fineness of grain of the added silica plays a more important part, with the addition of sand the rattler loss was increased, while in the case of the flint the rattler loss was reduced.

DISCUSSION

Mr. Blair: I should like to ask on what rattler charges these conclusions were based. For instance, were the rattler charges the same for the same character of sample?

Mr. Teetor: The rattler charges were the same throughout the experiment, the only variation being a slight difference in the total weight of the ten test pieces, which were rattled; this difference in no case exceeded but a few ounces.

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SOME COBALT-URANIUM COLORS

BY B. S. RADCLIFFE

There are four coloring oxides, namely, copper, chromium, nickel and iron, which under proper conditions produce green colors in bodies and glazes. In physical mixtures, we are able to produce greens by blending blue and yellow.

The object of this investigation was to determine whether green could be produced by blending cobalt-blue and uranium-yellow.

Series A was made up as follows:

TABLE I—SERIES A

	A_1	A_2	A_3	A_4	A_5
Co_2O_3	1.0	0.9	0.8	0.7	0.6
$Na_2U_2O_7$ 6 H_2O	50.0	50.0	50.0	50.0	50.0
$Al_2(OH)_6$	40.0	40.0	40.0	40.0	40.0
ZnO	25.0	25.0	25.0	25.0	25.0

The stains were thoroughly mixed, calcined to cone 5, ground to pass a 200 mesh screen and added to a mat glaze having the formula,

$$\left.\begin{array}{l} 0.1\ K_2O \\ 0.2\ CaO \\ 0.7\ PbO \end{array}\right\}\ 0.36\ Al_2O_3\quad 1.36\ SiO_2$$

The glaze was then burned to cone 05. The result was a yellowish green glaze with blue specks. This was due to the fact that the cobalt was not thoroughly disseminated.

A blue stain

Co_2O_3 10
Calc. Al_2O_3 45
ZnO 45

was then made, calcined to cone 7, and ground to pass a 200 mesh screen.

Three frits were made using the mat glaze as before.

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TABLE II—SERIES B

	B_1	B_2	B_3
Feldspar	17.6	17.6	17.6
$CaCO_3$	6.3	6.3	6.3
Red lead	50.5	50.5	50.5
Eng. china clay	11.0	11.0	11.0
Tenn. ball clay	10.0	10.0	10.0
Flint	4.6	4.6	4.6
Blue stain	10.0	10.0	10.0
$Na_2U_2O_7$ 6 H_2O	25.0	35.0	45.0

When applied as glazes, B 1 gave an olive green, B 2 and B 3 rich chocolate browns. These results indicate that the ratio of uranium to cobalt is too high.

The next step tried was to use the nitrates of cobalt and uranium, by fritting in the mat glaze.

TABLE III—SERIES C

	C_1	C_2	C_3
Feldspar	17.6	17.6	17.6
$CaCO_3$	6.3	6.3	6.3
Red lead	50.5	50.5	50.5
Eng. china clay	11.0	11.0	11.0
Tenn. ball clay	10.0	10.0	10.0
Flint	4.6	4.6	4.6
Cobalt nitrate	3.5	3.5	3.5
Uranium nitrate	10.0	12.0	15.0

The frits were ground, and a series of glazes made by blending with the original mat glaze.

Bright glazes were made by adding 20 parts of flint to the frits of this series.

The mat glazes were olive green, C_1 having a bluish shade.

Of the bright glazes C_3 was deep green in color, and C_1 and C_2 were green with a bluish shade.

Conclusions: Green glazes and mats can be made by blend-

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ing cobalt and uranium in the right proportions, which is between four and five parts of uranium nitrate to one part of cobalt nitrate.

Ceramic Laboratory,
University of Illinois.

DISCUSSION

Prof. Orton: I do not know, whether there has ever been any report made, about the peculiar green developed by one of the roofing-tile plants in this country by the use of cobalt oxide and sulphate of antimony. These coarsely ground chemicals were added to a roughly prepared glaze; and the result was that they succeeded in getting a very passable green. At least it looked like a good green on the roof, but if looked at close by, the size of the blue and yellow spots was so large as to be offensive. The reason, that they did this, was that they were working in a sulphurous close atmosphere, that spoiled other greens, and they thought, that if they had a sulphate to start with, it would not do any harm.

Mr. Radcliffe: I might say that a man in the terra-cotta business in Kansas told me that he used cobalt and uranium to produce greens. He did not tell me, however, until we worked it out. He was using it for polychrome work. The cobalt-uranium green that he produced was better than any other green that he could make for this purpose. It did not run or blend off with the white, but instead he could get a firm line between the green and the white, or whatever base was beneath the green polychrome work.

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THE USE OF MIXED POTASH-SODA FELDSPARS IN PORCELAINS

BY ARTHUR S. WATTS

There have been many interesting discussions at the meetings of this Society regarding the use of soda feldspars vs. potash feldspars, but we have no specific data with regard to the employment of a blend of these feldspars in porcelains. The French pegmatites contain much more soda feldspar than do the average American pegmatites and yet these porcelains, in which these pegmatites are employed, are matured at much higher temperatures than the American china and are fired according to European practice, i.e., low biscuit and high glost. This practice of firing is condemned in this country because it is supposed to cause so much more warping.

In order to ascertain just how practical such blends may prove, a series of porcelains was prepared in which all the variations between commercial potash and commercial soda feldspars were included.

ANALYSES OF MATERIALS USED

	POTASH FELDSPAR	SODA FELDSPAR	TENNESSEE BALL CLAY	ENGLISH CHINA CLAY	FLINT
SiO_2	69.45	65.50	51.20	47.37	99.18
Al_2O_3	16.76	21.17	32.10	37.85	....
Fe_2O_3	0.20	0.18	0.73	0.31	0.26
TiO_2	....	....	1.40	0.04	0.01
CaO	0.45	0.87	0.13	0.00	0.01
MgO	0.05	1.40	....	....	0.01
Na_2O	2.60	8.98	0.10	0.14	....
K_2O	9.80	1.00	0.69	1.40	....
Ignition Loss	0.28	0.15	13.75	12.60	0.11

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MINERAL COMPOSITIONS OF FELDSPARS

	COMMERCIAL POTASH SPAR	COMMERCIAL SODA SPAR
	PERCENT	PERCENT
Potash feldspar	58.70	6.00
Soda feldspar	25.15	83.86
Free quartz	16.15	10.14

The bodies included in the series were made in the ordinary wet way, and the feldspar and flint employed were all finer than 200 mesh screen.

The numbers and composition of the series were as follows:

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
	PERCENT	PERCENT	PERCENT	PERCENT	PERCENT	PERCENT	PERCENT
Potash feldspar.....	14.00	11.89	9.78	7.67	5.55	3.44	1.33
Soda feldspar.....	6.00	8.11	10.22	12.33	14.45	16.56	18.67
Tenn. ball clay.....	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Engl. china clay.....	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Flint	40.00	40.00	40.00	40.00	40.00	40.00	40.00

These bodies were made into bars of 1 in. by ½ in. by 4 in. and wedges of 1 in. by 3 in. varying from 1/32 to ¾ inch in thickness. The bars were scaled for shrinkage measurement and an additional set was employed for warpage trials. A complete set of trials was fired at cones 6, 8 and 10.

The warpage trials were supported on tiles seven and a half c.m. apart. The determination of warpage was made by stretching a rubber band across the concave face and measuring the actual warpage. This was then figured into percent. The shrinkage was obtained by actual measurement with a vernier scale.

The translucency was determined by placing the wedge-shaped trial over a one inch hole in a box containing a 16 candle power incandescent lamp of constant brilliancy. The maximum thickness of the trial, expressed in centimeters, through which a No. 20 wire can be detected on the face of the trial next the lamp

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with the lamp 3 inches distant, is taken as the measure of translucency.

The warpage measurements are as follows:

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
			CONE 6 BURN				
Actual .	1.5 m.m.	1.5 m.m.	2.5 m.m.	2.0 m.m.	2.0 m.m.	2.0 m.m.	1.5 m.m.
Percent	2	2	3.33	2.67	2.67	2.67	2.00
			CONE 8 BURN				
Actual .	1.5 m.m.	1.5 m.m.	3.0 m.m.	2.0 m.m.	2.0 m.m.	2.0 m.m.	1.5 m.m.
Percent	2	2	4.00	2.67	2.67	2.67	2.00
			CONE 10 BURN				
Actual .	2.0 m.m.	2.5 m.m.	3.25 m.m	3.25 m m	3.5 m.m.	4.0 m.m.	2.5 m.m.
Percent	2.66	3.33	4.33	4.33	4.67	5.33	3.33

The shrinkage measurements are as follows:

	No. 1 PERCENT	No. 2 PERCENT	No. 3 PERCENT	No. 4 PERCENT	No. 5 PERCENT	No. 6 PERCENT	No. 7 PERCENT
Cone 6 burn.....	12.0	14.0	14.0	14.0	14.0	14.0	14.0
Cone 8 burn.....	12.0	14.0	14.0	14.5	15.0	15.0	15.5
Cone 10 burn.....	13.0	14.5	15.0	17.0	17.0	16.5	16.0

The translucency measurements are as follows:

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Cone 6 burn.	0.444	0.466	0.487	0.507	0.528	0.530	0.530
Cone 8 burn.	0.543	0.573	0.591	0.601	0.637	0.662	0.611
Cone 10 burn.	0.490	0.500	.....	0.502	0.568	0.609	0.611

Conclusions. (a) Warpage. The above data indicates that the warpage is worst when about equal parts of soda and potash feldspar are used, providing the ware is not fired above cone 8, approximately 1290°C. If this temperature is exceeded, the

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warpage increases with soda feldspar content, until the soda feldspar exceeds 82.8 percent of the total feldspar content, then it decreases up to 100 percent soda feldspar. This indicates that if pure soda feldspar was used exclusively the warpage would be less than with any the natural mixtures of potash and soda feldspars.

(b) Shrinkage. Shrinkage increases with the soda feldspar content but only slightly so after the ratio equals one potash to one soda feldspar. If the firing temperature exceeds cone 8 the shrinkage increase is only up to a ratio of 61.65 percent potash and 38.35 percent soda feldspar. Beyond this the shrinkage decreases slightly.

(c). Translucency. Translucency increases with soda feldspar content, but when fired above cone 8 the translucency decreases with increased heat treatment in all members of the series studied.

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A ROPE HAULAGE PLANT COMBINING ELECTRIC POWER WITH GRAVITY

BY W. A. HULL

Mr. Riddle, in his valuable paper in Volume XV, describes an all-gravity system for handling clay on a down grade surface incline, in which the gradient of a portion of the tracks is so small that the gravity system will work only by virtue of the momentum gained during the first part of the trip. He shows that if the conditions were only a little more difficult, the gravity system would not operate at all. This suggests a modification of the all-gravity system, in which gravity is assisted in operating cars on an incline by means of a rope which is pulled by a power driven drum. An example of such a system in found in the Lookout Mountain Incline, which connects St. Elmo, near Chattanooga, Tennessee, with the town of Lookout Mountain, Tennessee, the latter located on the top of the mountain. This railroad is used for passenger traffic up and down Lookout Mountain. An all-gravity system of operation is out of the question, because the up-bound car may be loaded as heavily as the down-bound car, or more heavily than the latter. In most respects, the haulage problem corresponds closely with a clay haulage problem where the load travels up the grade or where the grades are such that a down-bound load will not pull an up-bound empty.

The equipment of this plant is somewhat more elaborate and expensive than would be either justifiable or necessary for handling clay, but the principles are the same in many respects. In this case, safety is the first consideration, and no expense has been spared in making the system almost automatic and practically accident proof.

The Incline Cable Railway, as it is called, is 4750 feet in length, and the difference in elevation between its upper and lower terminals is approximately 1500 feet. The average gradient is 35 percent, the minimum 10 percent and the maximum 67 percent.

The track is standard gauge and consists of 56 lb. tee rails

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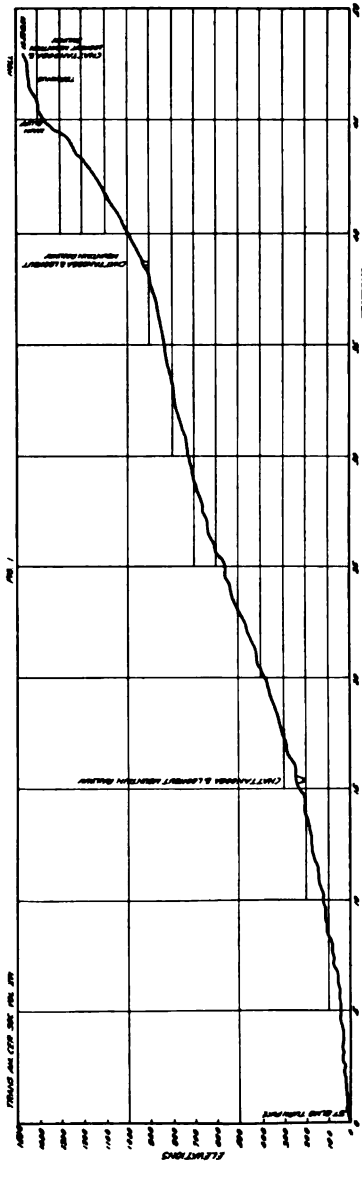

APPROXIMATE PROFILE OF THE LOOKOUT MOUNTAIN INCLINE AT CHATTANOOGA, TENN.

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laid on 6 in. by 8 in. ties, 8 ft. long where the track is single. A considerable part, particularly at the upper end, is on wood trestle, the rest being on solid earth. The trestling was made necessary to eliminate sudden changes in grade to which the cable, under tension, would not conform.

A turn-out is located half way between the terminal stations. From the lower terminal to the turn-out is a two rail track, while from the turn-out to the upper terminal, there are three rails instead of two individual double tracks. An important feature of the system is an ingenious arrangement of the switches of the turn-out which makes it possible, by having inside flange wheels on one car and outside flange wheels on the other, to dispense with any moveable parts at the turn-out switches.

The two cars are built on an angle to fit the average grade. They are 31 ft. 1¾ in. in length and carry forty-five passengers. These cars have an observation platform at the lower end; and they are lighted and heated electrically. Each car is equipped with a telephone, and the man in charge can also signal to the operator at the power house by making an electrical contact with a wire alongside the car. These cars are hoisted by means of an electrically driven hoist which consists of two electric motors of 130 H. P. each, operated at 550 volts, both geared to the same drum, over which two 1¼ in. steel cables are passed. The cables pass over this drum and an idle drum in turn, thus breaking the spiral or winding tendency. These two cables are worthy of special description, as they are used in an unusual way. They run throughout the course, side by side as a pair, or as one double cable, the purpose being that of safety. In case of a concealed weakness in one cable the other is counted on to hold the car. Something over a year ago, the wisdom of this precaution was demonstrated. One cable although apparently in good condition, did break, and the duplicate cable held the cars without giving the passengers any shock or alarm.

To each of the cars is attached one end of this double cable. As the drum arrangement is such that the cable is not attached to the drum and does not accumulate on it, the total length of the double cable is only a little more than the length of the in-

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cline. As one car goes down, the other comes up, the weight of one partially balancing the weight of the other.

The rope is carried on iron sheaves, 30 ft. apart and it runs on sheaves through the turn-out as well as on the straight track. Special, one-flange sheaves, long enough to give the rope a bearing all the time, are provided at the turn-out curves.

FIG. 2

The hoist is automatic in operation, and it is impossible to hoist a car past a given point at the head of the incline as the current is shut off gradually, as the car approaches the station, by means of a set of electric switches located in the track, which are tripped by the car as it enters the station.

Each car is equipped with an Otis double grip safety device capable of holding 50,000 lbs. This device is automatically controlled by a centrifugal governor which operates the safety device in case the speed of the car exceeds that for which the gov-

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ernor is adjusted. The safety device is also equipped with a hand operated mechanism which can be used by the conductor in charge of the car. The grip is designed to engage a 6 in. by 8 in. treated yellow pine stringer which is bolted to the outside of the track throughout its entire length.

A safety brake is also provided on the hoisting drum. This is operated by a centrifugal governor and can also be operated by the operator in charge of the power house. In case the man in control of the hoist were to drop dead, leaving the power on,

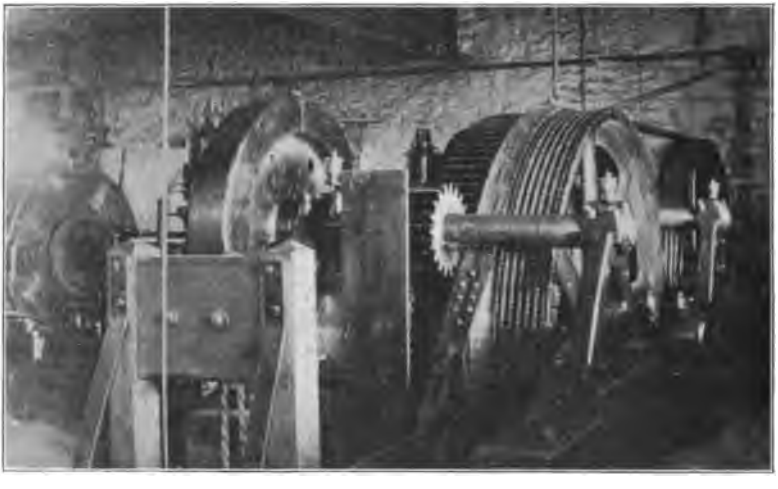

FIG. 3

the automatic safety brake would stop the apparatus if it exceeded the speed limit. If this did not occur, the car entering the station at the head of the incline would throw out the power by means of the automatic switches and stop the cars gradually, at the proper place.

This incline was built about eighteen years ago and has been in practically continuous operation since its completion. Until about three years ago, it was operated by a steam hoist. The operation has been satisfactory with both kinds of power, but the present equipment is simpler of operation and better safeguarded against possible accident than the former plant. In its eighteen

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years of operation, this incline railway has not experienced a wreck and has not hurt a person. It might be said without exaggeration that this record is worthy of emulation on the part of clay haulage inclines and some few of our "Safety First" steam railways as well.

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THE VERITAS FIRING RINGS[1]

BY A. V. BLEININGER AND G. H. BROWN, PITTSBURGH, PA.

The present work was done in order to supply information concerning the temperature range of a kind of refined draw trials, marketed under the name of "Veritas Firing System," and used in a considerable number of potteries and other clay plants. These trials consist of unburned rings of clay body, 2.5 inches in diameter, with a hole of about 0.85 inch, and of a composition approaching very closely that of white ware. These pieces are pressed from the body in the condition of moist dust, by means of a screw press, using a steel die. In using them, a number of the rings are placed in several parts of the kiln and drawn at different times during the burn. The diameter of the cooled ring is then measured by means of a simple device. In using the latter, the trial is placed against two pegs, on the other side, a lever, pressed forward by means of a spring, is held against the ring, which is thus kept in position by three points. The lever is about 8⅝ inches in length, and moves at its extremity along a scale, graduated into 60 equal divisions through an arc about 2⅞ inches in length. Any change in diameter is indicated in a magnified degree by the displacement of the pointer along the scale. The principle involved is, of course, not new, and was worked out in a most admirable way about 140 years ago by the famous potter, Josiah Wedgwood, in the form of the pyrometer connected with his name. Many other similar devices have been proposed, and it is a well known fact that shrinkage measurements have been used in the brick industry for many years as the most useful criterion of the progress of vitrification.

The present device was first described in detail by Marc Solon,[2] the inventor. Mr. Solon, in the article referred to, does not claim any great novelty in the principles of his method, but states that the advantages of this method of control consist, first, in being able to determine the progress of the firing at any time by the withdrawal of rings from certain parts of the kiln, so that

[1] By permission of the Director, Bureau of Standards.
[2] *The Pottery Gazette*, Oct. 1st, 1905.

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uniformity of burning may be maintained. Secondly, the shrinkage numbers indicate the actual heat work being done upon the body, so that the rate of firing may be accelerated during the period when little contraction is taking place and retarded when shrinkage is proceeding at its maximum rate. In this manner, the firing may be adjusted to the requirements existing at any time, which would not be possible by the use of a pyrometer, unless the most suitable rate of firing was previously determined. It is evident that, like the pyrometric cones, the firing rings cannot indicate temperatures. The more rapid the rate of firing, the higher must be the temperatures corresponding to the different shrinkage numbers, and vice versa. At the same time, however, it would seem desirable to correlate the contraction values indicated, with the temperatures for different rates of heating, in order to connect up the use of these trials with pyrometer practice. This is the object of the present work.

One of the requirements of a standard of this kind must be a practically uniform rate of contraction, since the same composition is to be used in plants making all sorts of products and using many kinds of clay. It is evident that any decided irregularities in this respect would tend to diminish the accuracy and usefulness of the system. Such fluxes as lime therefore must be avoided in the body used for these test specimens. The best mixture would probably be that of a white ware body, where the predominating flux is feldspar. Such a body is composed of about 52 percent of clay substance, 33 percent of flint and 15 percent of feldspar. By increasing the amount of feldspar, the range of the scale may be readily extended to porcelain.

In the preparation of such standards, it is necessary also to have available large quantities of the raw materials, thoroughly mixed, so that no undue variations may occur. Such factors as the fineness of grain of the feldspar and flint must be maintained constant, as well as the methods of preparation and pressing. Any decided change in the raw materials would make difficult the coordination of new mixtures with the old one, as the rate of contraction might be changed. However, by careful experiment-

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ing, it should be possible to produce stock, the properties of which would check with those of the standard mixture.

Forty of these rings were measured with a micrometer caliper, and the average diameter found to be 2.5065 inches. Measurements showed slight deviations from the circular shape but not sufficiently great to be corrected for in this work. The largest deviation in diameter was 0.0012 inch and the mean deviation 0.0004 inch. The weight of the rings varied from 48.55 to 50.70 grams, their thickness being, of course, of no consequence. The measuring scale has five divisions to the left of the zero point, so that somewhat larger rings than the standard size may be measured, although the specimens of each shipment are always of the same caliper. Each division of the scale corresponds to a mean value of 0.0054 inch, as measured upon the specimen. Measurements of the scale by means of a microscope comparator showed considerable and irregular variations in the graduation. The measurements could be made with a device capable of greater accuracy such as a modified micrometer caliper.

In determining the shrinkage of the rings at different temperatures the question of rapidity of firing was taken into consideration, and four firings were made at the constant rates of increase, of 12.5°, 16.6°, 25° and 50°C. per hour. The burns were made in one of the gas-fired test kilns of the laboratory having a capacity of about 28 cubic feet. The temperature was controlled carefully by means of two thermo-couples, one of which was connected to a recording and the other to a non-recording Siemens-Halske millivoltmeter. The cold junctions were kept at the ice-point. A suitable opening was provided in the wicket for the removal of the rings, two of which were taken out at each drawing temperature. Upon cooling, the rings were measured by means of a micrometer caliper, reading to 0.0001 inch and by the Veritas instrument. Three readings were taken of every ring, and the average of these used.

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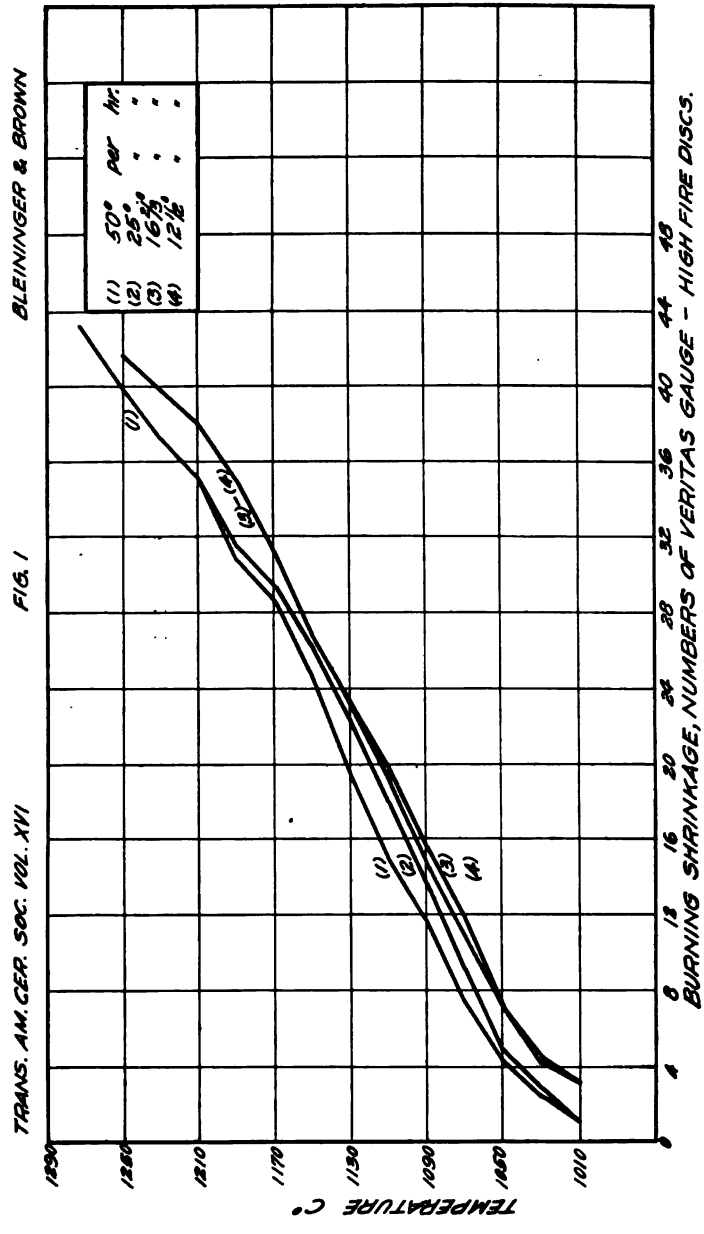

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The results of this work are compiled in Table I:

TABLE I. VERITAS FIRING SYSTEM—HIGH FIRE DISCS

	BURNING SHRINKAGE—INCHES				SHRINKAGE NUMBER			
TEMP. °C	RATE 50° PER HOUR	RATE 25° PER HOUR	RATE 16 2-3° PER HOUR	RATE 12½° PER HOUR	RATE 50° PER HOUR	RATE 25° PER HOUR	RATE 16 2-3° PER HOUR	RATE 12½° PER HOUR
1010	0.0110	0.0124	0.0191	0.0208	1.37	1.50	3.00	3.50
1030	0.0175	0.0184	0.0257	0.0263	2.50	2.50	4.12	4.50
1050	0.0279	0.0303	0.0403	0.0395	4.37	5.00	7.12	7.00
1070	0.0427	0.0499	0.0595	0.0647	7.50	9.20	11.00	11.87
1090	0.0636	0.0746	0.0785	0.0823	11.75	13.75	14.75	15.87
1110	0.0815	0.0945	0.1034	0.1041	15.00	18.00	19.25	19.75
1130	0.1035	0.1183	0.1205	0.1201	19.50	22.25	23.00	23.00
1150	0.1325	0.1404	0.1416	0.1418	24.87	26.12	26.62	26.75
1170	0.1525	0.1571	0.1680	0.1656	28.75	29.25	31.12	30.75
1190	0.1666	0.1699	0.1892	0.1895	31.00	31.50	35.00	34.87
1210	0.1863	.....	0.2056	0.2061	34.50	.....	37.75	38.00
1230	0.2018	.....	0.2198	0.2175	37.12	.....	40.00	40.00
1250	0.2165	.....	.....	0.2297	39.75	.....	.....	41.75
1270	0.2285	.....	.....	.....	41.50	.....	.....	.....

These values are also presented in graphical form in Figures 1 and 2, in which the shrinkage is expressed in the numbers of the Veritas instrument and in inches as measured by means of the micrometer caliper.

From the curves it appears, that the rate of shrinkage is quite regular, and hence the composition answers very satisfactorily the purpose for which it is intended. Measurements were not taken at lower temperatures, since the changes, as far as a body of this kind is concerned, are of no particular importance during the lower heat ranges. It might be stated also, that the instrument shows very distinctly the expansion occurring coincident with dehydration, though this point is not one of special significance as far as the control of burning is concerned. Upon comparing the four curves it will be noted that the time factor manifests itself in quite a marked manner. It will be observed that the temperatures at which equal contraction takes place are

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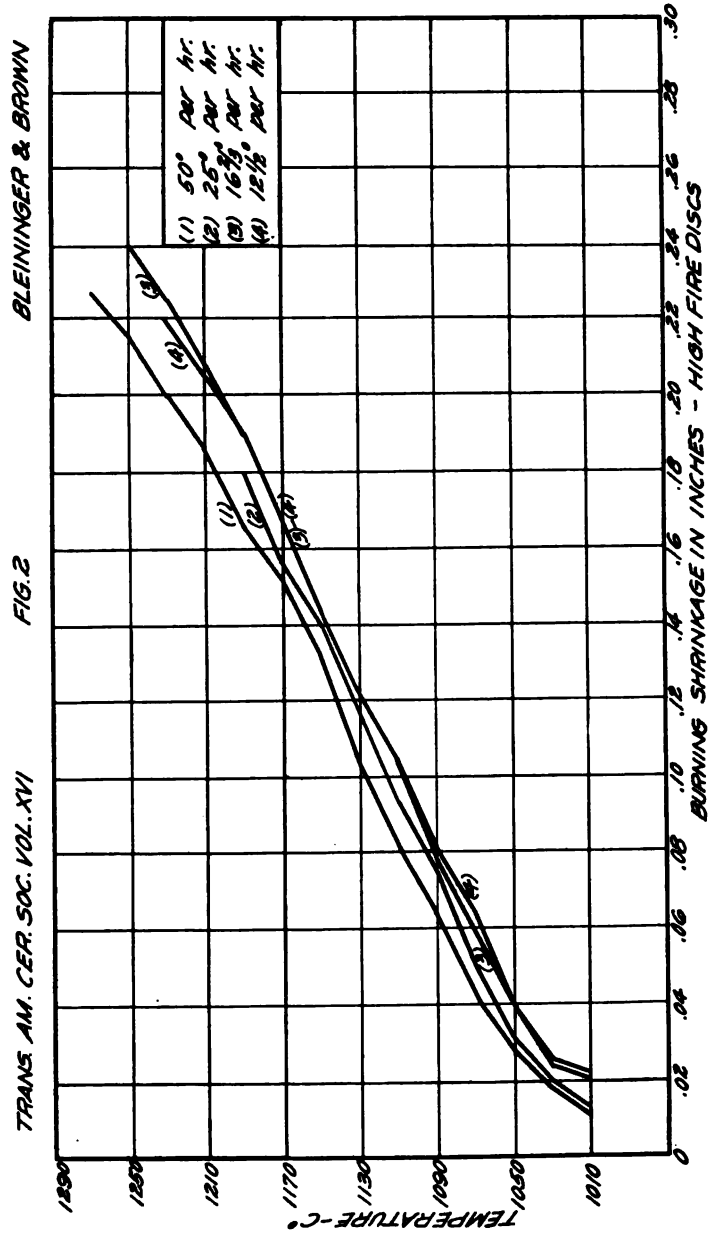

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the higher, the more rapid the rate of firing. These differences seem to diminish as the temperature rises. The firings at the rate of 12½° and 16⅔° per hour, tend to coincide as is to be expected, since the heat absorption approaches a constant value.

In this connection, it was thought desirable also to trace the connection between the porosity and the firing temperature, at the firing rates previously mentioned, and these are coordinated in the diagram of Fig. 3. These show parallelism with the contraction curves and bring out the same evidence, though the curves are differentiated somewhat more sharply.

The firm placing these pyrometric firing rings on the market has brought out also a series intended to be used at lower temperatures. A set of these was tested similarly to the method described for the higher temperature specimens, but using only the 12.5° and 25° per hour firing rates. The results of this work are presented in Fig. 4. From this curve, it would appear that this series does not show a regular behavior throughout the temperature range in question. At least four rates of contraction may be observed. Between 950° and 1070°C. the contraction progresses very slowly, which is a serious drawback, as this particular temperature interval is a very important one for the firing of red burning clays. It would seem then, that owing to this irregularity, the accuracy of control would be seriously impaired within this interval, since the slight contraction indicated might lead to the underestimation of the heat effects bringing about all important changes in the ware itself. It would be possible, however, to prepare a body which would show more consistent contraction than the one selected.

The standard firing rings of the higher temperature series are undoubtedly useful in controlling the firing of kilns, and if used in connection with a pyrometer, would tend to make the latter a far more valuable instrument. They offer a simple means of correlating heat work and the rate of temperature increase, and their use in this connection would be very beneficial. The principle of the system is sound, and the body selected has been well chosen for the firing of pottery kilns. The selection of the body for the lower temperature series has not been so successful,

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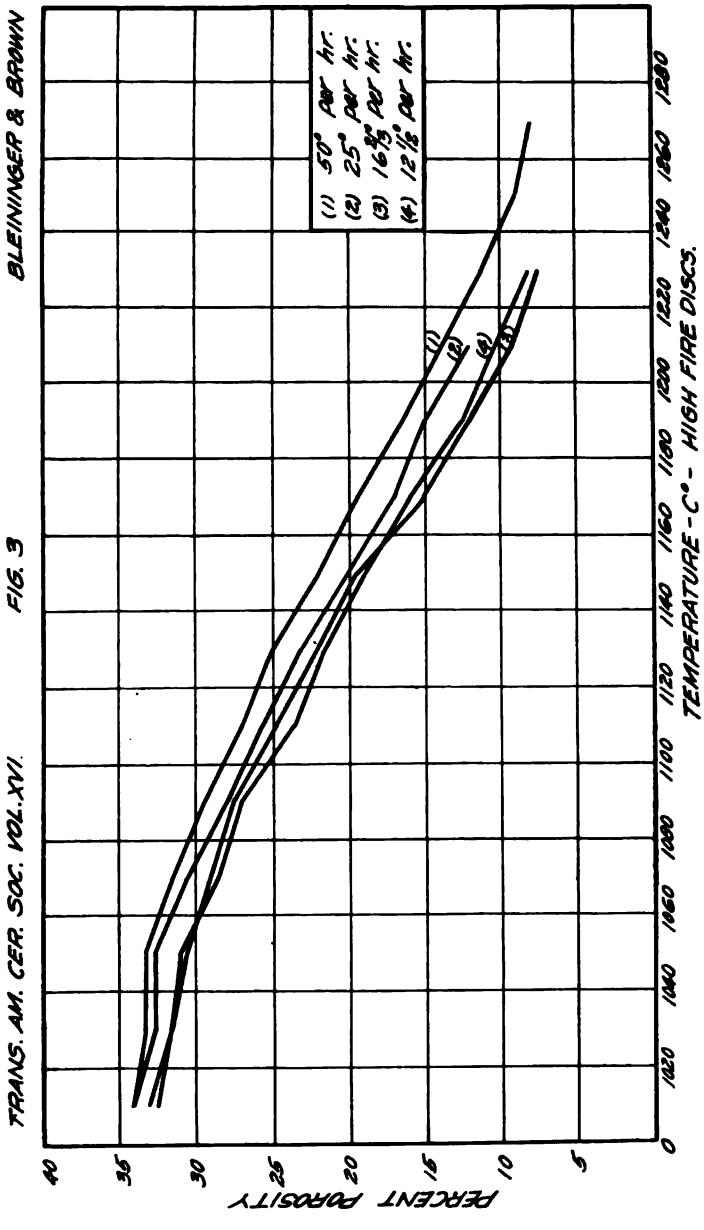

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and, as has already been stated, there are serious objections to its use.

For the control of the burning of all kinds of clay ware, draw trials of this kind could be prepared from the clay or body of which the ware itself is made. It is evident that such specimens would be of greater service for determining the progress of firing than any other body. In order to make the trials comparable with each other, they must be made from a well mixed standard sample of the material and pressed under the same conditions. In this connection, regularity of the shrinkage curve with temperature is not necessary, as it would be in the case of standards used in firing all sorts of clays. In fact the very peculiarities of the contraction of such clay trials would be useful in checking the burning behavior of the same material made into ware.

The thanks of the writers are due the Veritas Firing System Co. and the Trenton Potteries Co. for supplying the rings used.

DISCUSSION

Mr. Denmead: I wish to ask Mr. Bleininger, whether he found the Veritas disc trials proved the claim that they swelled in the early period of the firing and returned to normal as soon as the water is off.

Mr. Bleininger: Every clay body will expand during dehydration, and this is indicated by the instrument.

Mr. Denmead: They claim, that you can know exactly what your kiln conditions are, and that you can tell by their use exactly when the water is driven off the ware.

Mr. Bleininger: Yes, dehydration is clearly indicated.

Mr. McDougal: We are using this system in New Castle. We are making the rings of our own body, and we notice this initial swelling. Mr. Bleininger mentioned, that if your own body composition were used, calibration would be advisable. Even if this is not done, the rings, which are drawn at regular intervals from the four corners of the kiln, give as good as indication as you might want of the progress your ware is making, due allowance being made for the lag of the ware on account of

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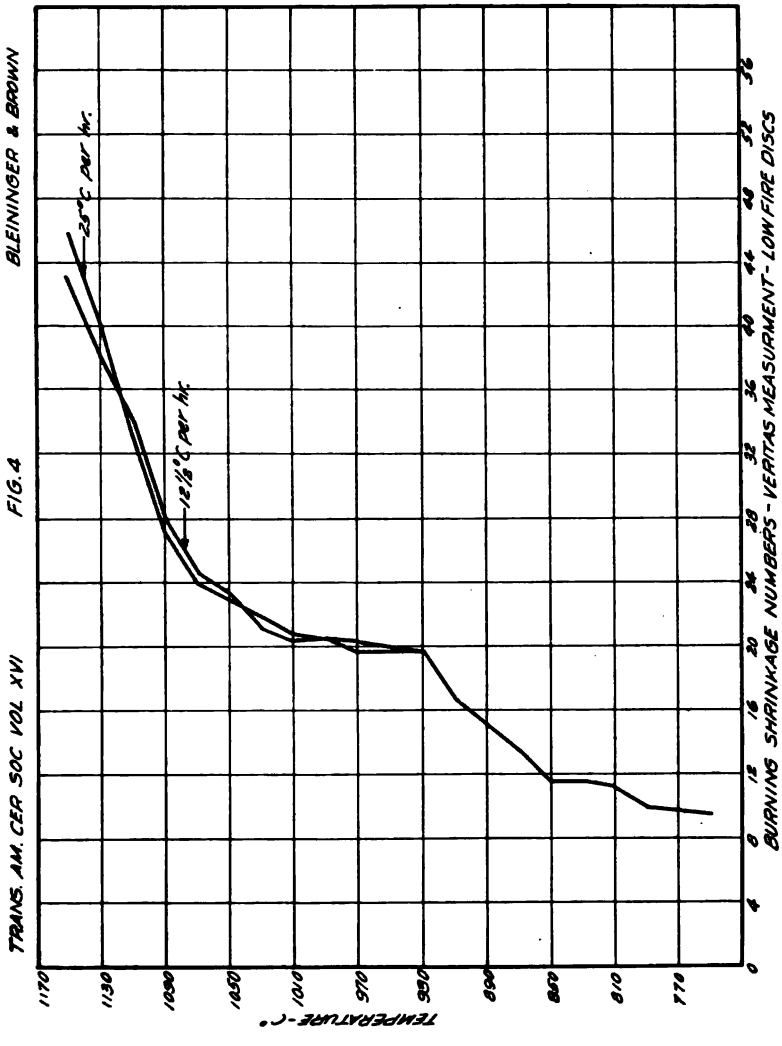

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the heat not reaching it as quickly as in the trials. I understand that there is a patent covering some phase of these rings. Is that true?

Mr. Bleininger: I do not know. I have not paid any attention to this matter.

Mr. Bowman: You will, I think, find the Veritas firing rings of service in determining the rate at which the heat in the kiln is progressing. We do not fire off our kilns by the Veritas ring, but merely use them as a check against the Seger cone.

Mr. Hill: I want to ask the exact temperature at which the discs cease to shrink. Have you a record of that?

Mr. Bleininger: None other than that given in the tables and curves.

Mr. Hill: We found the discs very satisfactory in checking up the kilns, especially new kilns just started. We do not use them continuously.

Mr. McDougal: I might add another word to what has been said. We find these rings of value in keeping a permanent record. After a kiln has been fired off, the rings still tell their story of the rate at which the firing was done. It is not always a true story, as the fireman realizing the increase is too rapid may pull his trials early.

Mr. Watts: I have heard the statement made by a number of men who introduced these rings that they are useless beyond the first ring. I have not any conception of a pyrometer or any other device of this sort that could be valuable in the first ring and not beyond it. Can anyone give me any light as to why they are not?

Mr. Allen: I think that the chief trouble is the inconvenience in having to reach in so far to draw. If you reach with a long iron rod it gets very warm and is then a difficult proposition to handle.

Mr. Nies: I should like to know the approximate composition of the rings, that is, whether they are a natural clay or refractory minerals with a binder.

Mr. Bleininger: They are a body mixture. We analyzed the rings and know what they are, but I do not believe that we

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should state the composition without the permission of the owners of the system. They are a body very much like the average white-ware body, and any such pottery body would give similar results. The one difficulty in any system of this sort is the question of uniformity—as to whether they can be maintained uniformly of this composition—because it is evidently not only the mineral composition but the physical structure also that is involved. This can be got around by a recalibration.

Mr. Purdy: It is no secret at all, that these rings are manufactured by the Cook Pottery Company, of Trenton, and are evidently of the same material as in their ware.

Mr. Watts: It is not so; they are not.

Mr. Minnemann: Regarding variation, the maker of the rings told me that after you use up the first batch and order the second, it is advisable to keep some of the first lot and check them against the second so as to correct any variation of a degree or two that may occur.

Mr. Miller: We have used, not the discs manufactured by the Cook Pottery Company, but some manufactured by our own plants, and with very good results. One objection that has been brought out to-day is that they are not useful except in the first ring. We have found them quite as useful in the inner rings of the kiln. We use them as far as the third ring and also in the second. We employ them in connection with the cones, using one to check up the other. We have found them to give a better record of the rate of our fire particularly in the early stages of it, where we would not use as low temperature cones as these discs. They give a constant record of what our night man does in every stage of the kiln; and it has materially bettered our product, so far as loss from rapid firing is concerned.

Mr. Lovejoy: Is it the pottery body used by the Cook Pottery Company that is employed in the manufacture of these discs?

Mr. Miller: It is not our pottery body.

Mr. Pence: I might add a word concerning my experience with these trials. We found them very good for medium to high temperature firing. We tried out one shipment of a small sam-

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ple order, and having used these up, we placed another order for a small amount. We found a difference, between the second shipment and the first, in the shrinkage obtained, of about two degrees. Therefore the point made by Mr. Minnemann of checking up one shipment against another applied in this case. However, we found that by using one of our bodies as the material for manufacturing the shrinkage discs, we got as good results as from the Veritas discs. The point made by Mr. Miller concerning the record of the firing we found to be the most important feature of the system. We have an accurate record of the progress of the kiln, to which we can refer for purposes of assurance and explanation. However, in determining the finishing point of bisque fires, pyrometric cones are found to be more sensitive than Veritas discs. Regarding the low-fire results, I would say that we have used a disc of a composition quite different from that of a Veritas disc, making it of a cruder clay composition, and have found it of distinct service in lower fires.

Mr. Miller: I should like to state another point with regard to the discs. We have always found that the rate of shrinkage of these discs was more rapid if we fired quickly. In fact, if we used these low-temperature discs in the glost kiln, we frequently found it to go out with the discs registering as high as our biscuit.

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POTTERY CASTING APPARATUS AND OTHER IMPROVEMENTS

BY HERFORD HOPE, BEAVER FALLS, PA.

Last year the writer set down under the title of "Shop Notes" a heterogeneous collection of items connected with the work of the clay shop, which he thought might possibly be of interest to some of the members of the Society, though he had serious doubts as to whether the majority, and particularly those of his own branch of ceramics, the whiteware potters, would not think them commonplace. Certainly none of them are epoch making; but after all, the pottery business is one vast mass of little details, and any improvement, however small, should be noted. Fortified by this apology, the writer will describe a few small improvements which have been put into use during the past few months. These consist of a caster's revolving table, a punch for cutting holes of various sizes and shapes in clay ware, an arrangement for washing out plaster pitchers automatically, and a clamp for holding certain mold cases, both of the latter having been designed by our moldmaker, W. W. McDanel.

CASTER'S ROTARY TABLE

By reference to Figure 1, it will be readily understood that this table is essentially a rotary stoveroom, full description of which is given in another article in this volume. It has, however, only three tiers of shelves, the fourth from the bottom (about 2 ft. 10 in. from the floor) being replaced by a solid flat top consisting of boards cut radially. The inner ends of these boards rest on 1 in. by 2 in. strips which are nailed to the center post, while the outer ends rest on the upright boards which form the ends of the shelves. A strip of oak is screwed from one upright board to the other, to give support to the top boards between the shelves. The top is divided into 24 equal spaces by means of pieces of 2 by 4's set on edge and kept in place by oak strips screwed to the table top. As shown in the illustration,

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the molds are held in place by wedges, and since the 2 by 4's are set radially, and run in to the center a distance of 18 in., they are adapted to molds of various sizes. The illustration shows the hopper, into which the surplus slip is poured from the molds, one of which is seen inverted across the top. Below is a steam connection which has to be used at times when the drain becomes clogged, a condition arising from the long distance and slight fall in this particular case, the slip draining back to the blunger where it was mixed. The slip pump used is illustrated in Figure 2, which shows the apparatus fairly clearly. The pump is automatic, working only when the pressure is low, and stopping by back pressure. The connecting rod is made in two parts, the lower and smaller part being fitted at its upper end with a flange or collar, and sliding within a cylinder which is, itself, attached to the eccentric and is always in motion. So long as the pressure keeps the lower rod at such a height within the upper part, that the collar does not engage, the pump does not work. As soon as the weights below overcome the back pressure, the lower rod is pulled down for the down stroke, and it is pulled up by means of its collar for the up stroke. That is, the down stroke is made by gravity, the up stroke by power. At first, considerable trouble was experienced by reason of air bubbles forming in the ware when the slip was poured into the molds, this being caused by the comparatively high pressure—a matter of 55 to 60 lbs., which was then used. By reducing the pressure to about 45 lbs. and at the same time increasing the size of the delivery hose from ½ in. to 1¼ in., the difficulty has been overcome to a large extent. The advantage of using a table such as that just described is evident, since the caster need not move a step either to fill or to empty his molds. With very little trouble, an arrangement can be made to fill several molds at once, as they pass under a given point, though as yet this has not been actually done. The lower part of the table, is in fact a stoveroom, and is ample for drying all molds used, steam pipes being provided as with other stoverooms.

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FIG. 1

FIG. 2

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PUNCH FOR CUTTING HOLES OF VARIOUS KINDS

This was designed especially for cutting the slots in match safe hoods, but it is equally suitable for holes of all sizes and shapes. Such work as the notching of covers for soup and sauce tureens and mustard pots is effected in a fraction of the time required to do it with a knife. It is of the usual hand punch form, but with jaws sufficiently long to carry the cutting edges of the required size and shape. The cutting edges may be made from hard sheet brass or other suitable material as thin as is consistent with durability ($\frac{1}{64}$ in. thick will answer), and these are soldered or otherwise fixed to the jaws. The jaws should be bored out to the same size and shape as the cutting edges to allow the punched-out piece of clay to be pushed through them. The cutting edges project each about 5/16 in. beyond the inside surface of the jaws, thus separating the latter by about $\frac{5}{8}$ in. In order to prevent bending or other detriment to the cutting edges, a set screw passes through the top jaw, and thus the adjustment of the two edges may be made accurately. (Figure 3.)

Fig. 3

Not only does the punch save a great deal of hand work, but from the fact that the two cutting edges meet in the center of the thickness of clay, all roughness on the outside is avoided, which is the result if the cutting is done from one side only.

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FIG. 4

FIG. 5

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PLASTER PAIL WASHING APPARATUS

This arrangement, which is shown in Figures 4 and 5 with and without a pail being washed, is of much convenience to the mold-maker, as it enables him to tend to his cases immediately after filling them, levelling the plaster and inserting sinkers (in the case of flat molds) while his plaster pail is being washed out automatically.

The operation of washing out the pail by hand either takes the moldmaker's time when he should be attending to the cases just filled, or necessitates the employment of a boy who, while he is given other work to do as well, might be dispensed with, were it not for washing out the pails. Instead of filling a slush tub with the plaster washings, the automatic washer carries everything out, through a 2 in. drain pipe passing through the bottom of the tub. The apparatus itself consists of a ½ in. pipe introduced through the bottom of the tub and rising to a height of 2 feet above the bottom. The pipe is plugged at the top and is surmounted with an old valve wheel which supports the bottom of the pail when the latter is inverted over it. A hollow ball would be far preferable to the wheel used in this instance, so that when perforated at equal intervals it would throw streams of water in every direction. In order to wash the spout of the pail, a pipe of equal size and also plugged at the end, is connected with the upright pipe at a distance of 8½ in. from the top by means of a tee, and bent downwards at about the same angle as the spout of the pail. This, as well as the upper part of the upright pipe, is perforated with 1/32 in. holes about an inch apart.

The efficiency of the apparatus depends much upon the water pressure, that in use being from 60 to 70 pounds, and it is hardly sufficient. If ¾ inch pipe were used with a pressure of 90 to 100 pounds, the results would be better. Care should be taken that sufficient drop be given to the drain pipe, in order that all waste plaster may be flushed out, though this will easily be done if the water is sufficient.

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CLAMPS FOR HOLDING PRESSED JUG CASES

In making jugs, covered dishes, or other molds for presser's use, it is quite usual either to nail blocks to the bench at suitable distances and after inserting the half cases, to wedge them at one end, or in some cases to tie them around completely after placing cottles of clay on each side. In still other cases, a

FIG. 6

complete case is made of plaster, leaving only a hole at the top for pouring. The latter, while more mechanical than the other methods, is open to the objection that the case takes longer to make and is much heavier, than when cottles are used. A convenient clamp for holding a case consisting only of the hump and end-gates, is that shown in Figure 6. It consists of a board 8 in. by 30 in., raised an inch or so from the bench and having a slot ½ inch wide for about half its length. At the opposite end is bolted a triangular block about 2½ in. wide, 6 in. high and 6

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in. base, its face sloping back at about 5 or 6 degrees from the perpendicular (to permit the insertion of wedges). Along the slot travels a similar block which may be held securely at any desired place by means of a thumb nut underneath the board. This arrangement permits instant adjustment of the block to a case of any length. The cottles used, consist of stiff linoleum to which are fastened, parallel with the case, strips of wood about 1 in. by 1 in. A wider piece set on edge is used about half way up, so as to enable the cottles to be tied tightly, this being effected by means of a cord and wire fastener.

DISCUSSION

Mr. Bleininger: Speaking of pottery equipment, I have frequently wondered why the potters did not make use of modern filter presses. They have now on the market a number of filter presses that seem to me to be very economic devices. I am referring particularly to the clam-shell filter press which minimizes labor to a large extent. I see no reason why a filter press of this type should not be used. The clam-shell press is composed of a cylindrical shell in which the filtering disks consist of perforated plates on which the filtering cloth is placed. By means of a pump or compressed air, the slip is forced into this cylinder and filtered. As soon as the cakes have formed, the excess slip is run off. The shell is then opened, and within ten seconds the whole charge is removed by air pressure. Within a short time the filter press is ready for operation. I think that something of this sort could find a place in the pottery industry.

Mr. Purdy: The use of a filter press spoken of by Mr. Bleininger would do away with the piling up of leaves as the potters now do and would perhaps be necessary where they use a car for drying prior to dry-pressing as in the tile business. I see no reason why they could not dump the clay and transport it to their cellar in lumps or spadings.

Mr. Lovejoy: I saw the application of the potters filter press in treating the slimes from the cyanide process in the works of the Homestake Mining Company at Lead, S. D. The filter plant is at Deadwood, several miles from Lead, and the cyanide

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plant is at Lead. The output of the mine at the time I was there several years ago was four thousand tons a day, all of which went through the stamps. The tailings went to the cyanide plant, and all the slimes from there went to the filter plant at Deadwood. There the slimes were put through the filter presses, which were our potters filter presses on a large scale. It is my recollection that there were about two thousand tons of material filter-pressed a day. They were not after the residue, but instead saved the solution which contained a trace of gold. After they had forced the water out and pumped it back into the tanks instead of opening the leaves as the potters do, water was pumped through the press in such a way as to wash out the mass of material.

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A DEPARTMENT OF CERAMICS IN THE OREGON SCHOOL OF MINES

BY IRA A. WILLIAMS

The Board of Regents of the Oregon Agricultural College has recently established in the School of Mines, which is a part of the College, a Department of Ceramics. This is the first of the far west state educational institutions to equip a department and offer a course of instruction in the ceramic field.

This step was taken by the governing board of the Agricultural College in response to a demand for ceramic work among students of the School of Mines and of the engineering departments of that institution. There is a growing recognition in the west of the importance of the ceramic industries. Clay wares of various kinds, and Portland cement are consumed in much larger quantities in Oregon than the state now produces. Needed encouragement, therefore, in the developing of these industries made the creation of the department the more urgent.

The Oregon State Legislature at its last session passed a bill creating the Oregon Bureau of Mines and Geology and providing 40,000 dollars for its maintenance for two years. A prominent feature of the bill is a provision for "an investigation of the clays of Oregon—as well as testing of all the clay manufactured products." Also "an investigation of limestones, shales, clays of Oregon, to determine their fitness for use as cement materials."

In carrying on the work of this new Bureau, the entire laboratory equipment of the various departments in both the Agricultural College and the University of Oregon has been made available for whatsoever purpose required, in the investigation of the mineral resources of Oregon. It was at once realized that an investigation of Oregon's ceramic materials should be given early attention.

In equipping the laboratories of the Ceramic Department of the School of Mines, therefore, the general plan has been to provide for doing investigational and experimental work as well

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FIG. 1. SCHOOL OF MINES BUILDING

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as for giving instruction in ceramic subjects. At present, two kilns have been installed, one a small rectangular down draft using crude oil and the other a Caulkins Revelation pottery kiln designed to burn kerosene. A dryer in which conditions can be accurately regulated is also to be installed.

The machinery equipment consists of a combination dry-wet pan, small blunger, filter press, ball mills, and other grinding machines, rolls, screens, potter's wheel and an auger machine provided with dies for making full size side and end cut brick, hollow block, drain tile and roofing tile. A hand power screw press with dies for dry press brick and flat tile; a Hoskins electric furnace for high temperature work, elutriator, balances, and various other pieces of apparatus for physical and chemical testing of clays and other ceramic materials, are also a part of the laboratory equipment. A twenty horse-power motor furnishes the necessary power. The ceramic laboratories occupy most of the available room on the basement floor of the Mines Building.

The design of the ceramic course is such as to prepare young men to make intelligent search for suitable raw materials, to make proper tests of them and to aid in their economic exploitation as well as to give them a fundamental knowledge of the processes of manufacture and qualities of the various ceramic products. The ceramic course is one of four years, the technical work being given largely in the junior and senior years. During the first two years ceramic students are required to take the same preliminary courses in the basic sciences and engineering subjects, as are students in chemical and mining engineering. The degree conferred on graduation from the ceramic course is Bachelor of Science in Ceramics. Technically speaking, the ceramic field is one that is wide open in the Pacific Coast states and one in which there is promise of rapid development.

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FIG. 2. VIEW IN CERAMIC LABORATORY

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THE EFFECT OF VARIATION OF RO ELEMENTS UPON CHROMIUM OXIDE AS A COLORING AGENT IN A MAT GLAZE

BY R. H. MINTON, METUCHEN, N. J.

A number of papers appearing in the Transactions discussing the effect of zinc oxide upon chromium oxide in glazes and stains, leads me to present from my notes, the results of a short series of experiments conducted in the summer of 1907, at the plant of the Perth Amboy Terra Cotta Co. The experiments were to determine the effect of calcium oxide, barium oxide and magnesium oxide, as well as zinc oxide, separately and in combination, upon chromium oxide in a certain type of mat glaze.

As this work was done previous to the appearance of Bryan's paper (Vol X, p. 124, *Trans. Amer. Cer. Soc.*), it has no bearing upon his work, except in further proving his conclusions regarding the influence of zinc oxide.

The method of application of terra cotta glazes by the air spray is so unhealthful, and the experience with lead glazes by the Perth Amboy Company, previous to my engagement there, had been so disastrous, that I have always avoided the use of lead in compounding such glazes. No especial merit is claimed for the type of glaze used in these experiments, it is merely a leadless-alumina mat producing a smooth texture at cone 4-5.

Method. Throughout the series, the K_2O, Al_2O_3 and SiO_2 are kept constant. The amount of chromium oxide is maintained at 1.75 percent of the batch weight of each glaze, this percentage being chosen because it was sufficient to produce a good green color. Through adding the chrome by percentage instead of by equivalent, the ratio to each glaze is kept constant.

In all cases the variable of the RO elements is maintained at 0.20 equivalent.

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TABLE OF FORMULAE

GROUP	NO.	PbO	K_2O	CaO	ZnO	BaO	MgO	Al_2O_3	SiO_2	Cr_2O_3 *percent*	REMARKS
I	1	....	0.20	0.80	....	....	....	0.35	2.25	1.75	
	2	....	0.20	0.60	0.20	....	....	0.35	2.25	1.75	
	3	....	0.20	0.40	0.40	....	....	0.35	2.25	1.75	
	4	....	0.20	0.20	0.60	....	....	0.35	2.25	1.75	
	5	....	0.20	....	0.80	....	....	0.35	2.25	1.75	
II	6	....	0.20	0.80	....	....	....	0.35	2.25	1.75	No. 6=No. 1
	7	....	0.20	0.60	....	0.20	....	0.35	2.25	1.75	
	8	....	0.20	0.40	....	0.40	....	0.35	2.25	1.75	
	9	....	0.20	0.20	....	0.60	....	0.35	2.25	1.75	
	10	....	0.20	....	....	0.80	....	0.35	2.25	1.75	
III	11	....	0.20	0.80	....	....	....	0.35	2.25	1.75	No. 11=No. 1
	12	....	0.20	0.60	....	....	0.20	0.35	2.25	1.75	
	13	....	0.20	0.40	....	....	0.40	0.35	2.25	1.75	
	14	....	0.20	0.20	....	....	0.60	0.35	2.25	1.75	
	15	....	0.20	....	....	....	0.80	0.35	2.25	1.75	
IV	16	....	0.20	....	0.80	....	....	0.35	2.25	1.75	No 16=No. 5
	17	....	0.20	....	0.60	0.20	....	0.35	2.25	1.75	
	18	....	0.20	....	0.40	0.40	....	0.35	2.25	1.75	
	19	....	0.20	....	0.20	0.60	....	0.35	2.25	1.75	
	20	....	0.20	....	....	0.80	....	0.35	2.25	1.75	No. 20=No. 10
V	21	....	0.20	....	0.80	....	....	0.35	2.25	1.75	No. 21=No. 5
	22	....	0.20	....	0.60	....	0.20	0.35	2.25	1.75	
	23	....	0.20	....	0.40	....	0.40	0.35	2.25	1.75	
	24	....	0.20	....	0.20	....	0.60	0.35	2.25	1.75	
	25	....	0.20	....	....	....	0.80	0.35	2.25	1.75	No. 25=No. 15

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TABLE OF FORMULA—Continued

GROUP	NO.	PbO	K_2O	CaO	ZnO	BaO	MgO	Al_2O_3	SiO_2	Cr_2O_3 *percent*	REMARKS
VI	26	....	0.20	....	....	0.80	....	0.35	2.25	1.75	No. 26=No. 10
	27	....	0.20	....	....	0.60	0.20	0.35	2.25	1.75	
	28	....	0.20	....	....	0.40	0.40	0.35	2.25	1.75	
	29	....	0.20	....	....	0.20	0.60	0.35	2.25	1.75	
	30	....	0.20	....	....	....	0.80	0.35	2.25	1.75	No. 30=No. 15
VII	31	....	0.20	0.20	0.60	....	....	0.35	2.25	1.75	No. 31=No. 4
	32	....	0.20	0.20	0.40	0.20	....	0.35	2.25	1.75	
	33	....	0.20	0.20	0.20	0.40	....	0.35	2.25	1.75	
	34	....	0.20	0.20	....	0.60	....	0.35	2.25	1.75	No. 34=No. 9
VIII	35	....	0.20	0.20	0.60	....	....	0.35	2.25	1.75	No. 35=No. 4
	36	....	0.20	0.20	0.40	....	0.20	0.35	2.25	1.75	
	37	....	0.20	0.20	0.20	....	0.40	0.35	2.25	1.75	
	38	....	0.20	0.20	....	....	0.60	0.35	2.25	1.75	No. 38=No. 14
IX	39	....	0.20	0.20	....	0.60	....	0.35	2.25	1.75	No. 39=No. 9
	40	....	0.20	0.20	....	0.40	0.20	0.35	2.25	1.75	
	41	....	0.20	0.20	....	0.20	0.40	0.35	2.25	1.75	
	42	....	0.20	0.20	....	....	0.60	0.35	2.25	1.75	No. 42=No. 14
X	43	....	0.20	0.60	0.20	....	....	0.35	2.25	1.75	No. 43=No. 2
	44	....	0.20	0.40	0.20	0.20	....	0.35	2.25	1.75	
	45	....	0.20	0.20	0.20	0.40	....	0.35	2.25	1.75	
	46	....	0.20	....	0.20	0.60	....	0.35	2.25	1.75	No. 46=No. 19
XI	47	....	0.20	0.60	0.20	....	....	0.35	2.25	1.75	No. 47=No. 2
	48	....	0.20	0.40	0.20	....	0.20	0.35	2.25	1.75	
	49	....	0.20	0.20	0.20	....	0.40	0.35	2.25	1.75	
	50	....	0.20	....	0.20	....	0.60	0.35	2.25	1.75	No. 50=No. 24
XII	51	....	0.20	....	0.20	0.60	....	0.35	2.25	1.75	No. 51=No. 19
	52	....	0.20	....	0.20	0.40	0.20	0.35	2.25	1.75	
	53	....	0.20	....	0.20	0.20	0.40	0.35	2.25	1.75	
	54	....	0.20	....	0.20	....	0.60	0.35	2.25	1.75	No. 54=No. 24

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XIII	55	....	0.20	0.60	....	0.20	....	0.35	2.25	1.75	No. 55=No. 7
	56	....	0.20	0.40	0.20	0.20	....	0.35	2.25	1.75	No. 56=No. 44
	57	....	0.20	0.20	0.40	0.20	....	0.35	2.25	1.75	No. 57=No. 32
	58	....	0.20	....	0.60	0.20	....	0.35	2.25	1.75	No. 58=No. 17
XIV	59	....	0.20	0.60	....	0.20	....	0.35	2.25	1.75	No. 59=No. 7
	60	....	0.20	0.40	....	0.20	0.20	0.35	2.25	1.75	No. 60=No. 72
	61	....	0.20	0.20	....	0.20	0.40	0.35	2.25	1.75	No. 61=No. 41
	62	....	0.20	....	....	0.20	0.60	0.35	2.25	1.75	No. 62=No. 29
XV	63	....	0.20	....	0.60	0.20	....	0.35	2.25	1.75	No. 63=No. 17
	64	....	0.20	....	0.40	0.20	0.20	0.35	2.25	1.75	No. 64=No. 76
	65	....	0.20	....	0.20	0.20	0.40	0.35	2.25	1.75	No. 65=No. 53
	66	....	0.20	....	....	0.20	0.60	0.35	2.25	1.75	No. 66=No. 29
XVI	67	....	0.20	0.60	....	....	0.20	0.35	2.25	1.75	No. 67=No. 12
	68	....	0.20	0.40	0.20	....	0.20	0.35	2.25	1.75	No. 68=No. 48
	69	....	0.20	0.20	0.40	....	0.20	0.35	2.25	1.75	No. 69=No. 36
	70	....	0.20	....	0.60	....	0.20	0.35	2.25	1.75	No. 70=No. 22
XVII	71	....	0.20	0.60	....	....	0.20	0.35	2.25	1.75	No. 71=No. 12
	72	....	0.20	0.40	....	0.20	0.20	0.35	2.25	1.75	No. 72=No. 60
	73	....	0.20	0.20	....	0.40	0.20	0.35	2.25	1.75	No. 73=No. 40
	74	....	0.20	....	....	0.60	0.20	0.35	2.25	1.75	No. 74=No. 27
XVIII	75	....	0.20	....	0.60	....	0.20	0.35	2.25	1.75	No. 75=No. 22
	76	....	0.20	....	0.40	0.20	0.20	0.35	2.25	1.75	No. 76=No. 64
	77	....	0.20	....	0.20	0.40	0.20	0.35	2.25	1.75	No. 77=No. 52
	78	....	0.20	....	....	0.60	0.20	0.35	2.25	1.75	No. 78=No. 27
XIX	79	0.20	0.20	0.60	....	....	....	0.35	2.25	1.75	
	80	0.40	0.20	0.40	....	....	....	0.35	2.25	1.75	
	81	0.20	0.20	0.40	0.20	....	....	0.35	2.25	1.75	
	82	0.20	0.20	0.20	0.40	....	....	0.35	2.25	1.75	

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Of necessity considerable duplication takes place from this arrangement, but as it was desired to maintain each group intact for convenience in studying results, the entire list of numbers was made, although of course No. 1, No. 6 and No. 11 were made from the same glaze batch, and like procedure for other duplications.

Materials Used:

Sparvetta spar, a soft soda spar mined by the Sparvetta Mining Co., Baltimore, Md.

English china clay No. 7 from Golding and Sons, Trenton, N. J.

Ohio flint from Golding and Sons, Trenton, N. J.

Paris white from American Whiting and Putty Co., New York City.

Red Seal zinc oxide from J. W. Coulston and Co., New York City.

Barium carbonate ppt. from R. and H. Chemical Co., New York City.

Light magnesium carbonate from R. and H. Chemical Co., New York City.

Green chromium oxide from R. and H. Chemical Co., New York City.

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TABLE OF BATCH WEIGHTS

GROUP	NO.	WHITE LEAD	SPAR	$CaCO_3$	ZnO	$BaCO_3$	$MgCO_3$	CHINA CLAY	SiO_2	BATCH WT.	Cr_2O_3
I	1	.....	111.4	80	....	....	....	38.7	45.0	275.1	4.81
	2	.....	111.4	60	16.2	....	....	38.7	45.0	271.3	4.77
	3	.....	111.4	40	32.4	....	....	38.7	45.0	267.5	4.68
	4	.....	111.4	20	48.6	....	....	38.7	45.0	263.7	4.61
	5	.....	111.4	..	64.8	....	....	38.7	45.0	259.9	4.55
II	6	.....	111.4	..	See No. 1	....	....	38.7	45.0	.....	....
	7	.....	111.4	60	....	39.4	....	38.7	45.0	294.5	5.16
	8	.....	111.4	40	....	78.8	....	38.7	45.0	313.9	5.49
	9	.....	111.4	20	....	118.2	....	38.7	45.0	333.3	5.83
	10	.....	111.4	..	....	157.6	....	38.7	45.0	352.7	6.17
III	11	.....	111.4	..	See No. 1	....	....	38.7	45.0	.....	....
	12	.....	111.4	60	....	....	16.8	38.7	45.0	271.9	4.76
	13	.....	111.4	40	....	....	33.6	38.7	45.0	268.7	4.70
	14	.....	111.4	20	....	....	50.4	38.7	45.0	265.5	4.64
	15	.....	111.4	..	....	....	67.2	38.7	45.0	262.3	4.59
IV	16	.....	111.4	..	See No. 1	....	....	38.7	45.0	.....	....
	17	.....	111.4	..	48.6	39.4	....	38.7	45.0	283.1	4.95
	18	.....	111.4	..	32.4	78.8	....	38.7	45.0	304.3	5.32
	19	.....	111.4	..	16.2	118.2	....	38.7	45.0	329.5	5.76
	20	.....	111.4	..	See No. 10	....	....	38.7	45.0	.....	....
V	21	.....	111.4	..	See No. 5	....	....	38.7	45.0	.....	....
	22	.....	111.4	..	48.6	....	16.8	38.7	45.0	260.5	4.56
	23	.....	111.4	..	32.4	....	33.6	38.7	45.0	261.1	4.57
	24	.....	111.4	..	16.2	....	50.4	38.7	45.0	261.7	4.58
	25	.....	111.4	..	See No. 15	....	....	38.7	45.0	.....	....

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TABLE OF BATCH WEIGHTS—Continued

GROUP	NO.	WHITE LEAD	SPAR	$CaCO_3$	ZnO	$BaCO_3$	$MgCO_3$	CHINA CLAY	SiO_2	BATCH WT.	Cr_2O_3
VI	26	.....	111.4	..	See No. 10	....	....	38.7	45.0	.....	....
	27	.....	111.4	..	....	118.2	16.8	38.7	45.0	330.1	5.77
	28	.....	111.4	..	....	78.8	33.6	38.7	45.0	307.5	5.38
	29	.....	111.4	..	....	39.4	50.4	38.7	45.0	284.9	4.98
	30	.....	111.4	..	See No. 15	....	....	38.7	45.0	.....	....
VII	32	.....	111.4	20	32.4	39.4	....	38.7	45.0	286.9	5.02
	33	.....	111.4	20	16.2	78.8	....	38.7	45.0	310.1	5.43
VIII	36	.....	111.4	20	32.4	....	16.8	38.7	45.0	264.3	4.62
	37	.....	111.4	20	16.2	....	33.6	38.7	45.0	264.9	4.64
IX	40	.....	111.4	20	....	78.8	16.8	38.7	45.0	310.7	5.44
	41	.....	111.4	20	....	39.4	33.6	38.7	45.0	288.1	5.04
X	44	.....	111.4	40	16.2	39.4	....	38.7	45.0	290.7	5.09
XI	48	.....	111.4	40	16.2	....	16.8	38.7	45.0	268.1	4.69
XII	52	.....	111.4	..	16.2	78.8	16.8	38.7	45.0	306.9	5.37
	53	.....	111.4	..	16.2	39.4	33.6	38.7	45.0	284.3	4.98
XIV	60	.....	111.4	40	....	39.4	16.8	38.7	45.0	291.3	5.07
XV	64	.....	111.4	..	32.4	39.4	16.8	38.7	45.0	283.7	4.96
XIX	79	51.6	111.4	60	....	....	....	38.7	45.0	306.7	5.37
	80	103.2	111.4	40	....	....	....	38.7	45.0	338.2	5.92
	81	51.6	111.4	40	16.2	....	....	38.7	45.0	302.9	5.30
	82	51.6	111.4	20	32.4	....	....	38.7	45.0	299.1	5.23

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DUPLICATIONS

GROUP	NO.	SEE	GROUP	NO.	SEE	GROUP	NO.	SEE
VII	31	4	XII	51	19	XVI	67	12
	34	9		54	24		68	48
VIII	35	4	XIII	55	7		69	36
	38	14		56	44		70	22
IX	39	9		57	32	XVII	71	12
	42	14		58	17		72	60
X	43	2	XIV	59	7	XVII	73	40
	45	33		61	41		74	27
	46	19		62	29	XVIII	75	22
XI	47	2	XV	63	17		76	24
	49	37		65	53		77	52
	50	24		66	29		78	27

Method of Compounding. Five times the batch weight in grams was made of each different glaze, and this ground wet for five hours in a porcelain Abbe ball mill, "Trojan" type. All glazes were brought to as near the same fluidity as possible, weighing about 24 ounces per pint.

Tile. The tile used were dry pressed biscuit wall tile 3 in. by 1½ in., supplied by The C. Pardee Works, Perth Amboy, N. J.

Application. The method of application was one heavy coat, hand dipped from end to end, similar to the old method in tile manufacture before the introduction of the glaze coating machines. No foreign adhesive substance was added. The edges were fettled, and the numbers marked on the backs of the tiles with an ordinary slate pencil, the mark of which burns to a permanent brick red color. Two sets were made in order to duplicate results, in separate burns in different kilns.

Burning. The trials were burned in the interior of 40 ton terra cotta kilns, requiring about 120 hours to burn and nearly as long to cool. Cone 4 down was reached at trials.

RESULTS FROM KILN

Group I—CaO and ZnO variables.

No. 1—Beautiful smooth mat. Slightly water-marked. Fine pea green color.

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No. 2—Dead mat surface. Zinc texture. Color slightly reddish brown.

No. 3—Semi-mat. Decided reddish brown color.

No. 4—Beautifully matured mat. Smooth as satin. Very fine drab color.

No. 5—Slightly rough surface. Not quite mature. Light fawn color.

Group II—CaO and BaO variables.

No. 6—Same as No. 1.

No. 7—Fine mat. Nile green. Darker green than No. 1. Crazed.

No. 8—Smooth surface, but broken, due to contraction. Apple green.

No. 9—Rough, but not harsh, alligator skin surface. Very dark chrome green.

No. 10—Rough, harsh surface. Hedge-apple green. Great difference in color between No. 9 and No. 10.

Group III_2CaO and MgO variables.

No. 11—See No. 1.

No. 12—Rough, harsh, broken surface. Pale faded green color.

No. 13—Rough, harsh, broken surface. Dark brown.

No. 14—Rough, harsh, broken surface. Light brown, faded edges.

No. 15—Rough, smooth, broken surface. Dark fawn. Darker than No. 5.

Group IV—ZnO and BaO variables.

No. 16—See No. 5.

No. 17—Very smooth, shiny surface. Broken. Dark brown, but without the slight reddish tone of No. 4.

No. 18—Smooth, slightly broken. Medium drab color.

No. 19—Rough and broken surface. Dark brown.

No. 20—See No. 10.

Group V—ZnO and MgO variables.

No. 21—See No. 5.

No. 22—Smooth, shiny. Fawn color, with gray tone.

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No. 23—Same as No. 22, but much duller surface.
No. 24—Rough. Trifle less pinkish than No. 15.
No. 25—See No. 15. Smoother than No. 24.

Group VI—BaO and MgO variables.

No. 26—See No. 10.
No. 27—Rough, harsh, broken. Greenish brown.
No. 28—Less matured than No. 27. Dirty gray color.
No. 29—Dry and immature. Light gray.
No. 30—See No. 15.

Group VII—CaO constant at 0.20 eq. ZnO and BaO variables.

No. 31—See No. 4.
No. 32—Very fine mat. Deep fawn color. Not so smooth as No. 31.
No. 33—Smooth, broken surface. Brownish gray color.
No. 34—See No. 19.

Group VIII—CaO constant. ZnO and MgO variables.

No. 35—See No. 4.
No. 36—Very fine surface. Slightly more pinkish than No. 32. Smoother.
No. 37—Fine texture. Lighter color than No. 36.
No. 38—See No. 14.

Group IX—CaO constant. BaO and MgO variables.

No. 39—See No. 9.
No. 40—Dull, broken surface. Very dark grayish green. Not nearly so green as No. 39.
No. 41—Dull, harsh surface. Light straw brown.
No. 42—See No. 14.

Group X—ZnO constant. CaO and BaO variables.

No. 43—See No. 2. Dead mat, reddish brown.
No. 44—Fine surface. Color like No. 32, but slightly more pinkish.
No. 45—Like No. 33.
No. 46—See No. 19.

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Group XI—ZnO constant. CaO and MgO variables.

No. 47—See No. 2.
No. 48—Fine surface. Fawn color. Very dark.
No. 49—Fine surface. More pinkish than No. 48.
No. 50—See No. 24.

Group XII—ZnO constant. BaO and MgO variables.

No. 51—Same as No. 19.
No. 52—Smooth and broken. Color, light wood brown.
No. 53—Smooth and broken. Light fawn color.
No. 54—See No. 24.

Group XIII—BaO constant. CaO and ZnO variables.

No. 55—See No. 7. Only showing green. Good texture.
No. 56—See No. 44. Good texture.
No. 57—See No. 32.
No. 58—See No. 17.

Group XIV—BaO constant. CaO and MgO variables.

No. 59—See No. 7. Fine green.
No. 60—Rough, harsh and broken, dark gray brown.
No. 61—See No. 41. Lighter than No. 60.
No. 62—See No. 29. Still lighter color.

Group XV—BaO constant. ZnO and MgO variables.

No. 63—See No. 17. Dark brown.
No. 64—Fairly smooth. Broken surface. Not quite so dark brown as No. 63.
No. 65—See No. 53. Still lighter thai No. 64.
No. 66—See No. 29. Gray, not brown.

Group XVI—MgO constant. CaO and ZnO variables.

No. 67—See No. 12. Rough, faded green.
No. 68—See No. 48. Smooth, dark fawn.
No. 69—See No. 36. Smooth, pinkish, fawn color.
No. 70—See No. 22. Smooth, shiny.

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Group XVII—MgO constant. CaO and BaO variables.

No. 71—See No. 12. Rough, faded green.
No. 72—See No. 60. Rough, grayish brown.
No. 73—See No. 40. Dull, grayish green.
No. 74—See No. 27. Rough, greenish brown.

Group XVIII—MgO constant. ZnO and BaO variables.

No. 75—See No. 22. Smooth, shiny. Fawn color.
No. 76—See No. 64. Medium brown shade.
No. 77—See No. 52. Light brown.
No. 78—See No. 27. Greenish brown.

Group XIX—PbO, CaO and ZnO variables.

No. 79—Very fine mat. Crystalline texture. Apple green. Texture not so smooth as No. 1.
No. 80—Good mat. Faint gloss. Very dark brownish green.
No. 81—Light wood brown. Dull, wrinkled texture.
No. 82—Very strong pinkish color. Pinholed bad. Quite shiny.

SUMMARY

Color.

Calcium alone produces fine green.

Calcium and zinc (in increasing amounts) produce from pinkish to brownish shades.

Calcium and barium produce very dark greens. Barium deepening green color decidedly.

Calcium and magnesium produce brownish shades.

Calcium and lead produce fine bright greens.

Zinc alone produces light fawn shades.

Zinc and barium produce brown shades.

Zinc and magnesium produce pinkish browns.

Zinc and lead produce brown and strong pink shades.

Barium alone produces yellowish or hedge apple greens.

Barium and magnesium produce grayish colors.

Magnesium alone produces fawn shades and seems to exert stronger effect upon Cr_2O_3 than zinc.

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Fluxing Properties.

Magnesium and barium are poor fluxes compared with calcium and zinc.

Calcium alone is superior to zinc, barium, or magnesium alone; none of the latter form good smooth mats, while calcium alone produces a fine texture.

Zinc and calcium together are much better than barium or magnesium with either calcium or zinc, although low barium with high calcium makes a smooth surface but crazes.

Calcium and magnesium together do not flux in any proportions.

CONCLUSIONS

Glaze No. 1 is undoubtedly a calcium-alumina mat, and according to Heubach[1] should not produce a green. My experience with a large variety of glazes colored with chrome compounds or chrome stains without zinc, lead me to believe that alumina in itself has no great effect upon the color. The other elements in the RO of the glaze exert a very decided effect; and probably high alumina does promote the influence of these, of which I mean zinc and magnesium especially.

Repeated trials have demonstrated to me, that a glaze containing not over 0.10 eq. zinc oxide and 2 percent Cr_2O_3 made up with say, 0.40 K_2O and 0.45 Al_2O_3 can be made to yield good, dark greens if properly fired; while another glaze maturing at the same heat, but composed of 0.25 K_2O and 0.35 Al_2O_3 with zinc oxide and chrome the same as before, almost invariably produces browns.

Most likely, the larger ratio of clay to spar in the latter glaze accentuates the action of the zinc, but in itself it is probably not the disturbing element. This may possibly be due to the clay engaging the action of the lime, leaving the zinc freer to exert a stronger influence upon the chrome. Zinc is a good thing to entirely eliminate from a glaze containing chrome, although I consider magnesium a useful RO element if confined to say 0.10 eq.

[1] *Trans. Amer. Cer. Soc.*, Vol. XIV, p. 428.

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There can be no question but that oxidation and reduction play the leading parts in the action of chrome, in glazes containing zinc. A glaze, containing 0.075-0.100 eq. ZnO and a percent Cr_2O_3 under normal oxidizing kiln conditions, will usually develop a brown, while under a strong reducing condition it will develop a strong dark green, thus overcoming the oxidizing action of the zinc oxide upon the chrome. Often both colors and all variations will come from the same kiln or even on the same piece, especially if two faces have been set very close together.

I question very much, however, if the length of burn or duration of cooling has much effect upon the development of the color. My explanation of Humphries' statement (Vol. X, p. 132, *Trans. Amer. Cer. Soc.*), regarding different results from trial and large kilns, is that in a small kiln where the heat is raised rapidly or forced, the kiln conditions are more apt to be reducing than in a slower fired large (particularly muffle) kiln, which normally is usually oxidizing. It is practically impossible to duplicate in large commercial kilns burning 80 to 120 hours the results from trial kilns reaching the same heat in 18 to 24 hours, and I long ago made it a rule to carry all experiments through the regular factory process.

ADDITIONAL NOTE ON CHROMIUM STAIN

Owing to the frequent wide variation in green colors obtained by the use of raw oxide of chrome, even when secured from the most reliable sources, I have found it safer to use stains in preference to the raw commercial chrome. This has led to many experiments with chrome stains of vastly different compositions; and in the light of this work, Pence's statement, (*Trans. Amer. Cer. Soc.*, Vol. XV, p. 120) that "It is demonstrated that the color effect of zinc upon chromium in underglaze stains is similar to the action of the same in glazes," is not convincing. I do not question the results which he exhibits, but they are not broad enough to be final and conclusive for all cases.

There can be no doubt that the action of zinc in a stain is influenced strongly by the "other elements" entering into the composition of the stain; and in some stains its influence is cer-

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tainly not so strong or effective, as when in a glaze. At the same time Heubach's statement, (*Trans. Amer. Cer. Soc.*, Vol. XIV, p. 429), that zinc oxide is detrimental only when incorporated in a glaze is exceedingly loose.

The following stain No. 3, composed of

50 Cr_2O_3
50 ZnO

which calcines to a soft, light chocolate brown color at cone 5, always produces a wood brown color when used to the extent of four or five percent in a glaze, either with or without zinc.

Stain No. 63, composed of

33⅓ zinc oxide
33⅓ chrome oxide
33⅓ flowers of sulphur
1 percent cobalt oxide (black).

produces a fine dark green when calcined to cone 5.

Stain No. 178, composed of

40 Cr_2O_3
20 ZnO
5 Co_3O_4
20 SiO_2
15 borax

produces a dark blue green at cone 5.

These last two stains I have used repeatedly in large and small amounts, with unvarying success in securing uniform color.

In stain No. 63 the ratio of zinc oxide to the chromium oxide is the same as in stain No. 3. Stain No. 3 is invariably brown and stain No. 63 always dark green. My theory has been that the sulphur combines with the oxygen in the zinc oxide, preventing it from oxidizing the chrome, to produce a brown color. I have never made any experiments to determine just how little sulphur could be used and still develop the green color. Acting on this theory, I have taken a mat glaze containing 0.35 eq. ZnO (about 10 percent of batch weight of the glaze) and 2 percent raw Cr_2O_3, which always produced a brown, and incorporated

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up to 10 percent flowers of sulphur in the glaze. The only difference I could detect was that the glazes containing the sulphur were of a more reddish brown than that of those free from sulphur. Ten percent of sulphur had no deleterious effect upon the glaze.

There can be no doubt that a stable chrome stain, whether green or brown, retains its own characteristic color to a large extent when incorporated in a glaze (containing no zinc, where the green stain is used). At the same time, the composition of the glaze can be made to exert a marked effect upon the resulting color. I have a fine chocolate brown stain produced from ZnO, Cr_2O_3, Fe_2O_3, B_2O_3 and SiO_2, which when incorporated in equal amounts in four different glazes maturing at the same temperature (cone) will produce four browns very unlike.

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SCIENTIFIC MANAGEMENT AND THE BONUS SYSTEM AS APPLIED TO POTTERY MANUFACTURE

BY C. J. KIRK, NEW CASTLE, PA.

I attended a meeting of this Society last year for the first time, and heard a number of papers about the scientific analysis of clays and the different articles that enter into the manufacture of pottery. Nothing was said about the scientific management of labor. Now, labor enters into our manufacturing costs as much as clays and other materials, and I think is just as important. We read in the magazines and trade papers about scientific management, shop efficiency and the bonus system, but I do not think that this plan has ever been applied to the pottery industry. Indeed, it cannot very well be, on account of the attitude of the unions; they will not permit it. About a year ago I read up on this subject, and then wrote to some of the people who are introducing it into manufacturing establishments. Mr. Taylor, of Philadelphia, is one of the chief exponents of the system, and I wrote and asked him, what he would charge to furnish me a young man to put it in at our pottery. He advised that the charges were fifty dollars a day, and that it would take about a year to install it.

Now I object very seriously to giving any person more money than I make myself, so I did not engage this young man, but went at it and worked out a system of my own, providing certain demerit marks for the different faults that happen to ware in a pottery. Under our old system, after we drew a kiln we held a court. The ware was brought out and set down, and each man was charged with any of his pieces that were defective. For some defects we charged the price of making it; and for some where it ruined the piece, double the price.

To reach just decisions by means of this court was always a very difficult matter. The man who made the defective piece said that it was the kiln fireman's fault, and the latter said it was the fault of the placer. The upshot of the matter was that

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TRANS. AM. CER. SOC. VOL. XVI — FIG. 1 — KIRK

KILN NO. 3 — INSPECTOR'S REPORT — DATE 4-14-13

Workmen	Pieces in Kiln	10 Finish	10 Hollow Cast	3 Trap Showing	5 Cracked Trap	5 Pegging	3 Inlet	5 Channel	2 Rimholes	2 Dunted Holes	10 Cracked Rims	Workmen	TOTAL	Average	Rank
11	16			II (6)	II (15)	II (10)	II (9)	I (5)	I (2)			11	47	3	1
14	37	220	I (10)	85	III (40)	III (45)	117	130		II (4)	III (30)	14	724	19.6	9
20	–											20	–	–	–
24	7			II (6)			III (15)	II (10)				24	36	5.1	2
25	–											25	–	–	–
28	16	III (90)		III (27)		I (5)	III (21)	III (35)				28	178	11.1	6
35	–											35	–	–	–
49	32	II (20)		68	I (5)	III (25)	III (42)	III (70)	I		III (30)	49	263	8.2	3
50	8		I (10)	III I (18)	I (5)	II (15)	III (12)	II (10)				50	70	8.8	4
57	–											57	–	–	–
59	9	III (40)		III (12)		III (25)	III I (21)	II (15)				59	113	12.5	7
60	–											60	–	–	–
61	–											61	–	–	–
65	–											65	–	–	–
66	8	III (30)		IIII (21)			III I (18)	III (15)				66	84	10.5	5
70	9	II (20)		III II (24)	II (10)	III II (35)	III I (18)	III (20)				70	127	14.1	8

142 Total Pieces — Average 11.60 — Total Points 1642

TRANS. AM. CER. SOC. VOL. XVI — FIG. 2 — KIRK

KILN NO. 2 — INSPECTOR'S REPORT — DATE 4-16-13

Workmen	Pieces in Kiln	10 Finish	10 Hollow Cast	3 Trap Showing	5 Cracked Trap	Pegging 5	3 Inlet	5 Channel	2 Rimholes	2 Dunted Holes	10 Cracked Rims	Workmen	TOTAL	Average	Rank
11	8						I					11	3	4	1
14	8	I (10)		IIII III (24)		III (15)	IIII (15)	IIII I (30)				14	94	11.8	12
20	22	IIII (50)		IIII (12)		I	IIII IIII (30)	IIII I (30)	I			20	129	5.9	4
24	14	IIII I (60)		IIII III (24)		IIII I (30)	IIII III (27)	IIII (20)				24	161	11.5	10
25	12	I (10)		IIII I (18)	I	I	III (9)			I		25	49	4.1	3
28	8	III (30)		IIII (12)		IIII (20)	IIII I (18)	III (15)				28	95	12.0	13
35	16			IIII II (21)			IIII II (21)					35	42	2.6	2
49	–											49	–	–	–
50	22	IIII (40)		IIII (15)	I	IIII I (30)	IIII IIII (36)	IIII I (30)			II (20)	50	176	8.0	5
57	7	III (30)		II (6)			I	II (10)			I	57	59	8.4	7
59	10	II (20)		IIII I (18)	I	IIII (25)	IIII III (24)	IIII (25)				59	117	11.7	11
60	15	III (30)	I	IIII IIII (30)		IIII I (30)	IIII III (27)	IIII (20)			I	60	157	10.5	8
61	–											61	–	–	–
65	8	I		IIII I (18)		II (10)		IIII I (30)				65	68	8.4	6
66	9	I		IIII I (18)		II (10)	IIII II (21)	IIII I (30)			I	66	99	11.0	9
70	8	I		IIII II (24)	I	IIII (20)	IIII I (18)	IIII (20)				70	97	12.1	14

167 Total Pieces — Average 8.06 — Total Points 1346

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it was not anyone's fault, and I would have to be called out to settle the dispute.

In this new system we charge a man so many demerits for each defect that appears on the ware. These demerits are based on the seriousness of the fault. For instance: for poor finish he is charged with ten demerits; hollow casting is another fault that receives ten demerits. If the piece does not remain in the mold long enough, it does not cast solid and sinks in when it is fired. Trap showing, gets three points. If the trap is set too far to one side or the other, it shows on one side of the closet. Cracked trap and poor pegging get five; the finish around the inlet three points. Where they finish it around the top they sometimes cut a channel, that is five points. Foot cracked through bolt holes, two points. Ware cracked in rim, ten points; dunting, two points.

We started this system on the first of last April, and Figure 1 is the first inspector's report from kiln drawn after that date. This kiln was drawn on the 14th of April. You will note that No. 14 was a very bad workman, and had 724 points against him. He was the only old union presser that we had in our shop. We are running a non-union shop. The 724 points against him were for this one kiln, and he had thirty-seven pieces in it. The column at the left shows the workman's number. We have some Italian casters, and No. 14 is the man who said that as long as we had Italian workmen, we would have trouble and have faults in the ware. Now, this record places him right away. When we make the record, each man has a little card made up with the number of demerits charged to him, and each fault that he had, and this card is pasted up in front of him so that he can see it all the time. At the end of the month we make a full report, showing the number of points against each man and his grade. The column at the right shows the number of defects; the next, the grade: 1st, 2d, 3d, 4th, and so on, up. At the end of the month we give the man who has the fewest demerit marks rank No. 1 and a bonus of five dollars; the man who has the next fewest demerits gets a bonus of three dollars; and the next, two dollars. That helps some, but it is not the real crux of the thing.

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TRANS. AM. CER. SOC. VOL. XVI — FIG. 3 — KIRK

KILN NO. 5 — INSPECTOR'S REPORT — DATE 5-14-13

Workmen	Pieces in Kiln	10 Finish	10 Hollow Cast	3 Trap Showing	5 Cracked Trap	5 Plugging	3 Inlet	5 Channel	2 Rim Holes	2 Dented Holes	10 Cracked Rims	Workmen	TOTAL	Average	Rank
11	–											11	–	–	–
14	–											14	–	–	–
20	16			IIII I (16)			I	IIII (20)			I	20	51	3.2	4
24	16			III (9)		I	IIII (12)	II (10)				24	36	2.5	2
25	24			IIII IIII (27)		IIII (20)	I	IIII IIII (40)				25	95	4.0	5
28	24			IIII IIII (33)	I	II (10)	II (6)	IIII IIII (30)				28	104	4.3	6
35	–											35	–	–	–
49	–											49	–	–	–
50	16			I	I	IIII (25)		I	I	I		50	42	2.6	3
57	24	I		IIII II (21)	II	II	I	IIII IIII IIII I				57	139	5.8	9
59	15			IIII (12)	I	II (10)						59	27	1.8	1
60	16			IIII I (16)		I		IIII IIII (35)				60	78	4.9	8
66	–											66	–	–	–
65	25	I		IIII II (28)		IIII II (35)	I	IIII II (35)		II (4)		65	111	4.4	7
66	29			IIII IIII IIII (40)		III (25)	I	IIII IIII IIII (50)				66	176	6.0	11
70	16			IIII IIII (30)		IIII II (40)		IIII (25)				70	95	5.9	10

221 Total Pieces — Average 4.36 — Total Points 964

11th

TRANS. AM. CER. SOC. VOL. XVI — FIG. 4 — KIRK

KILN NO. 4 — INSPECTOR'S REPORT — DATE 6-10-13

Workmen	Pieces in Kiln	10 Finish	10 Hollow Cast	3 Trap Showing	5 Cracked Trap	5 Plugging	3 Inlet	5 Channel	2 Rim Holes	2 Dented Holes	10 Cracked Rim	Workmen	TOTAL	Average	Rank
11	–											11	–	–	–
14	15				I	I	IIII I (15)					14	28	1.86	11
20	17				I						I	20	15	.88	6
24	24					I						24	5	.20	2
25	16				IIII (25)					I		25	27	1.68	10
28	16										II	28	20	1.25	8
35	–											35	–	–	–
49	–											49	–	–	–
50	16				II (10)							50	10	.62	5
57	16				III (15)							57	20	1.25	8
59	16				I				I			59	7	.43	3
60	16	II (20)			I							60	25	1.56	9
61	8				IIII (25)							61	30	3.75	12
65	10											65	0	0	1
66	25										I	66	15	.60	4
70	16				III (18)		I					70	18	1.12	7

211 Total Pieces — Average 1.04 — Total Points 220

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When we post this record in the casting shop, the men "guy" each other. They say: "You are a bum workman," to the fellow that is at the bottom, and he is prompted by his egotism to get up a peg. I think that this has more to do with the improvement made than the bonus.

Figure No. 1 is the inspector's report on the first kiln drawn after the new system went into effect. That was on the 14th of April. Figure No. 2 is on the second kiln, made two days later, on the 16th. The average number of points against each piece of ware in the first kiln was 11.06. This man, No. 14, dropped from 724 points to 94 in the second kiln; and the average dropped to 8.6 from 11.6. Part of the ware in kiln No. 1 was made before the men knew that the bonus system was going into effect, but the ware in Figure No. 2 was probably all made, after they knew about it.

Figure No. 3 is a report some thirty days later. Other reports had come in between, and the average dropped first to seven, and then to six, and had come down constantly with every kiln drawn. In this kiln, Fig. No. 3, which, as I have said, was drawn thirty days later than the second one shown, the average dropped to 4.36.

Figure No. 4 is a report made sixty days later, and the average has dropped to 1.4, and you see that the sheet is clearing up. This is a pretty clean sheet. Figure No. 5 was made thirty days after the preceding one, and the average has dropped to .9—less than one percent. Number 6 is thirty days later still, with an average of .68. We are getting pretty nearly perfect ware now, six-tenths of one percent. Figure No. 8 is a report showing an average of .21, about one-fifth of one percent of demerits. That was made November 14th.

Up to the first of November we had a man that inspected each piece of ware, before it went to the kiln. Then we decided that he was not needed, so we let him go. We thought that after this the average would run up again. It was then running .65, .68 and along there. After we gave up the inspection, however, it dropped down to one-fifth of one percent, because the men depended on themselves instead of on an inspector. That is our

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TRANS. AM. CER. SOC. VOL. XVI — FIG. 5 — KIRK

KILN NO. 2 — INSPECTOR'S REPORT — DATE 7-18-13

Workmen	Pieces in Kiln	10 Finish	10 Hollow Cast	3 Trap Showing	5 Cracked Trap	5 Pegging	3 Inlet	5 Channel	2 Rim Holes	2 Dented Holes	10 Cracked Rims	Workmen	TOTAL	Average	Rank
11	17					III (15)						11	15	.88	8
14	8						I					14	3	.37	3
20	15						III (9)					20	9	.60	6
24	7				I							24	5	.71	7
25	14				I		I				I	25	8	.57	5
28	–											28	–	–	–
35	16				I	I						35	20	1.25	10
49	16											49	0	0	1
57	–				III (15)							57	–	–	–
50	16											50	15	.93	9
59	16			I	II · (10)	III (15)	I					59	31	1.93	11
60	24			I	II (10)							60	13	.54	4
61	–											61	–	–	–
65	12				III (15)	III (15)	I					65	33	2.75	12
66	–											66	–	–	–
70	8											70	0	0	2

169 Total Pieces — Average 0.90 — Total Points 152

TRANS AM CER SOC. VOL. XVI — FIG. 6 — KIRK

KILN NO. 2 — INSPECTOR'S REPORT — DATE 8-12-13

Workmen	Pieces in Kiln	10 Finish	10 Hollow Cast	3 Trap Showing	5 Cracked Trap	5 Pegging	3 Inlet	5 Channel	2 Rim Holes	2 Dented Holes	10 Cracked Rims	Workmen	TOTAL	Average	Rank
11	21				II (10)	I						11	15	.71	5
14	7											14	10	1.42	9
20	10						III (9)					20	9	.90	6
24	8											24	0	0	2
25	–											25	–	–	–
28	8											28	0	0	2
35	23				III (20)	I						35	25	1.08	7
49	28											49	0	0	1
50	8											50	0	0	2
57	7											57	0	0	2
59	10	I		II (6)	I						I	59	31.	3.10	10
60	9			I								60	3	.33	3
61	–											61	–	–	–
65	10			III (9)		I						65	14	1.40	8
66	8											66	0	0	2
70	8					I						70	5	.62	4
71	–											71	–	–	–

165 Total Pieces — Average 0.68 — Total Points 112

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record, .21. We have nothing better than that, and it runs between that point and .40. I have a report with me, taken on the 28th of February, which shows .28.

I think that this demonstrates the value of a record of that kind and of the bonus system; and I also think that it points out the way to solve the problem of union labor. This system makes the best man set the pace in your shop. In the union shop, on the contrary, the poorest workman sets the pace. When we ran

TRANS. AM. CER SOC VOL. XVI — FIG. 7 — KIRK

KILN NO. 2 — INSPECTOR'S REPORT — DATE 10-30-13

Workman	Pieces in Kiln	10 Finish	10 Hollow Cast	3 Trap Showing	5 Cracked Trap	5 Plugging	3 Inlet	5 Channel	2 Rim holes	2 Dunted Holes	10 Cracked Rims	Workman	TOTAL	Average	Rank
11	24					I						11	5	.21	4
14	-											14	-	-	-
20	16				III (15)							20	15	.90	7
24	16					I						24	5	.31	5
25	8											25	0	0	3
28	8											28	0	0	3
35	24											35	0	0	1
49	16					II (10)					I	49	20	.125	9
50	8											50	0	0	3
57	9	I				-				I		57	12	.133	11
59	21			I	II (10)	II (10)				II (4)		59	27	.128	10
60	-											60	-	-	-
61	-											61	-	-	-
65	16											65	0	0	2
70	16					I						70	5	.31	5
71	-											71	-	-	-
48	16	I					I					48	13	.81	6
66	24	III (30)										66	30	.125	8

222 Total Pieces — Average 0.60 — Total Points 132

a union shop, a presser made three siphon jet closets a day. This is all he could make, that is, the poorest workman could, but a good workman could make four or five. They would not, however, allow him to do that. This system has changed the whole atmosphere in the shop. The men are now striving to make good ware.

I confess that these results are a great surprise to me. I was a little skeptical about scientific management and the bonus system, when I first went at it, but the results have justified the trouble that we went through to put it in, and it can be adapted to any line of manufacture.

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TRANS AM CER SOC. VOL XVI — FIG. 8 — KIRK

KILN NO. 2 — INSPECTOR'S REPORT — DATE 11-14-13

Workmen	Pieces in Kiln	10 Finish	10 Hollow Cast	3 Trap Shaving	5 Cracked Trap	5 Pegging	3 Inlet	5 Channel	2 Rimholes	2 Dunked Holes	10 Cracked Rims	Workmen	TOTAL	Average	Rank
11	24											11	0	0	1
14	11						1					14	3	.27	7
20	25				11 (10)	1						20	15	.8	9
24	8									1		24	2	.25	5
25	8											25	0	0	4
28	–											28	–	–	–
35	16					1						35	5	.31	6
49	24											49	0	0	1
50	24											50	0	0	1
57	–											57	–	–	–
59	16				1							59	5	.31	6
60	–											60	–	–	–
61	8											61	0	0	4
65	16				1		1					65	8	.5	8
66	8										1	66	10	1.25	10
70	16											70	0	0	3
71	–											71	–	–	–
48	22											48	0	0	2

226 Total Pieces — Average .021 — Total Points 48

TRANS. AM CER SOC. VOL XVI — FIG 9 — KIRK

KILN NO. 1 — INSPECTOR'S REPORT — DATE Jan. 6, '14

Workmen	Pieces in Kiln	10 Finish	10 Hollow Cast	3 Trap Shaving	5 Cracked Trap	5 Pegging	3 Inlet	5 Channel	2 Rimholes	2 Dunked Holes	10 Cracked Rims	Workmen	TOTAL	Average	Rank
11	–											11	–	–	–
14	–											14	–	–	–
20	36											20	0	0	1
24	29	IIII (40)					1 (3)			1 (2)		24	45	1.55	9
25	26					1 (5)						25	5	.19	6
28	21	1 (10)	1 (10)			1 (5)						28	25	1.19	8
35	–											35	–	–	–
49	–											49	–	–	–
50	28											50	0	0	2
57	41				1 (5)		1 (3)					57	8	.19	5
59	–											59	–	–	–
60	–											60	–	–	–
61	–											61	–	–	–
65	–											65	–	–	–
66	8									1 (2)		66	2	.25	7
70	4											70	0	0	4
71	–											71	–	–	–
48	22											48	0	0	3

215 Total Pieces — Average 0.40 — Total Points 83

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DISCUSSION

Mr. F. W. Walker, Sr.: I should like to ask Mr. Kirk whether No. 14 is still working for him.

Mr. Kirk: Yes, he took the prize last month. We made a good workman out of him. He now has ware come out of the kiln without any faults. He did not like the others to get ahead of him.

Mr. Truman: How many men do you employ, Mr. Kirk?

Mr. Kirk: We employ thirty casters.

Mr. Truman: You apply that system just to the casters?

Mr. Kirk: Yes, sir.

Mr. Minnemann: I should like to ask Mr. Kirk whether the loss of less than one-half percent is the total loss in the kiln, and whether he has any trouble in crediting the loss on each piece to the particular man responsible for it? Is there never any question?

Mr. Kirk: There is no controversy at all. We do not hold a court. The inspector puts down the faults, and we have no trouble; that is eliminated.

Mr. Shaw: I understand that this is the ware after it comes from the kiln, and that the defects are noted and placed upon the shoulders of the man whose number that piece of ware bears. Does one man cast the ware, and also finish it and glaze it?

Mr. Kirk: No, this is the inspection from the biscuit kiln.

Mr. Shaw: Each man handles his own piece of ware and casts it and finishes it for the kiln?

Mr. Kirk: Yes, and we pay good from the kiln.

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THE COMPRESSION, TENSILE AND TRANSVERSE STRENGTH OF SOME CLAYS IN THE DRIED STATE[1]

BY A. V. BLEININGER AND W. L. HOWAT, PITTSBURGH, PA.

In work now being carried on in our laboratory, a number of the tests applied to clays in the dried state are to be examined. In this respect, two classes of tests must be distinguished, the direct tests upon the materials in the plastic state, and the indirect methods to which they are subjected in the dried state. It is evident that those of the second class are not entitled to be called plasticity tests, proper. Still, they are of considerable interest, inasmuch as they express the mechanical strength of the clays when dried, and since it is a fact that, broadly speaking, the more plastic clays show greater strength than the leaner ones. Although a considerable number of such tests, especially relating to tensile strength, have been published, it was thought desirable to compare a number of typical clays, with reference to their tensile, compression and transverse strength, taking care to use a larger number of specimens than is common and maintaining closely controlled conditions of drying. At the same time, it was considered advisable to improve the drying conditions by using mixtures of the materials with standard Ottawa sand, so largely employed in cement testing, in the proportion of 1 : 1, by weight. In this manner the question of bonding power is introduced, which is closely related to plasticity. The grains of this sand correspond to the size retained between the 20 and 30 mesh sieves.

In all cases a sufficient quantity of clay for making up the specimens used in all three of the tests was prepared by pugging in a wet pan. The clay was kept in a moist chamber in the shape of a large lump from which the required amounts were taken for the molding of the pieces.

The tensile briquettes were molded by hand in the usual manner, in brass molds. The shape of the specimens differed

[1] By permission of the Director, Bureau of Standards.

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TABLE I—TENSILE STRENGTH TESTS

		A—WITHOUT SAND					B—WITH SAND					
NO.	CLAY	WATER CONTENT PERCENT	MAX. LBS. SQ. IN.	MIN. LBS. SQ. IN.	AVERAGE LBS. SQ. IN.	AVERAGE DEVIATION FROM MEAN PERCENT	WATER CONTENT PERCENT	MAX. LBS. SQ. IN.	MIN. LBS. SQ. IN.	AVERAGE LBS. SQ. IN.	RANK	AVERAGE DEVIATION FROM MEAN PERCENT
1	M. & M. Ball No. 1	36.6	248.0	181.0	210.0	7.6	19.4	205.5	175.0	190.0	1	3.8
2	W. Va. Shale	18.5	224.0	153.5	187.0	7.7	10.9	88.5	69.0	77.0	12	4.6
	W. Va. Shale	18.5	191.0	131.0	(158)	7.3	....	.....	.....	.....	..	...
3	Whitaway Ball Clay	35.1	197.0	121.0	161.0	13.5	17.5	175.0	140.0	152.0	3	3.7
4	Kittanning No. 2 Fire Clay	16.3	182.0	132.0	155.0	6.1	12.0	127.5	94.0	113.0	7	8.1
	Kittanning No. 2 Fire Clay	16.3	200.5	146.0	(172)	6.7	....	.....	.....	.....	..	...
5	M. & M. Ball No. 11	37.2	174.5	128.0	154.0	9.0	20.6	176.0	139.0	158.5	2	5.0
6	Georgia Kaolin (a)	29.8	173.0	134.5	147.0	7.3	15.1	122.0	100.5	110.5	9	5.4
7	Cleveland Shale	19.9	176.0	115.0	141.0	8.8	12.8	125.5	92.5	111.0	8	6.7
	Cleveland Shale	19.9	167.0	130.0	(148)	4.1	....	.....	.....	.....	..	...
8	Canton Shale	21.1	166.0	114.0	136.0	7.9	12.5	115.0	88.0	101.0	10	8.7
	Canton Shale	21.1	153.0	102.0	(126)	6.8	....	.....	.....	.....	..	...
9	Great Beam Ball	35.8	166.0	112.5	135.5	8.2	18.7	142.0	113.0	127.5	5	5.8
10	Tenn. Ball No. 1	34.4	141.0	110.0	125.0	5.5	18.2	141.5	102.0	124.0	6	6.7
11	Georgia Kaolin (b)	29.6	158.5	67.5	109.0	13.8	14.8	108.0	87.0	97.5	11	6.5
12	Florida Kaolin	40.8	121.0	82.5	104.0	9.2	20.7	62.0	47.5	54.0	13	5.5
13	N. C. Kaolin	31.8	85.0	56.5	69.0	11.1	16.6	41.0	29.0	34.9	14	7.6
14	M. G. R. China Clay No. 2	36.7	48.0	33.2	40.5	6.2	18.3	28.8	24.2	26.1	16	4.4
15	M. W. M. China Clay	37.6	40.2	29.6	34.3	8.4	19.3	34.6	25.4	28.8	15	9.9
16	No. 3 Ohio Fire Clay	....	....	....	....	....	11.0	174.0	124.0	150.4	4	5.4
				Average	.....	8.17				Average	.....	6.1

NOTE: Parentheses indicate machine molded.

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from the one commonly used, and was the one employed by the Germans, the essential difference consisting in a groove at the center of the narrow portion. This was found to be a satisfactory shape resulting in better breaks than are obtained with the ordinary cement briquette. In a number of cases, additional test pieces were made by attaching the briquette mold to a small auger machine and pressing a bar of clay which was then cut into the required thickness, 0.9 inch. These pieces are designated as "machine made."

In all cases the specimens were allowed to dry at room temperature for one week, then at 75° C. to constant weight in a gas dryer, and finally at 110° C. in an electrically heated Freas oven with automatic temperature control, according to the method proposed by Kerr. The pieces were tested, immediately after removal from the dryer and cooling in a desiccator. The briquettes were broken in an apparatus built in our machine shop, provided with an automatic shut-off for the shot, illustrated in Fig. 1. This device was found to be considerably more accurate than the use of the Fairbanks or similar cement testing machine.

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TABLE II—COMPRESSION TESTS

		A—WITHOUT SAND					B—WITH SAND					
NO.	CLAY	WATER CONTENT PERCENT	MAX. LBS. SQ. IN.	MIN. LBS. SQ. IN.	AVERAGE LBS. SQ. IN.	AVERAGE DEVIATION FROM MEAN PERCENT	WATER CONTENT PERCENT	MAX. LBS. SQ. IN.	MIN. LBS. SQ. IN.	AVERAGE LBS. SQ. IN.	RANK	AVERAGE DEVIATION FROM MEAN PERCENT
1	M. & M. Ball No. 1.....	36.6	1281.0	1005.0	1148.0	6.0	19.4	871.0	703.0	777.0	1	6.9
2	M. & M. Ball No. 11.....	37.2	1227.0	947.0	1056.0	6.6	20.6	650.0	465.0	556.0	4	10.7
3	No. 3 Ohio Fire Clay.....	16.6	1024.0	848.0	954.0	4.8	11.0	640.0	465.0	553.0	5	9.1
4	Whitaway Ball.....	35.1	862.0	721.0	806.0	5.0	17.5	693.0	567.0	623.0	2	5.2
5	Cleveland Shale.....	21.2	903.0	675.0	806.0	6.6	12.8	528.0	372.0	449.0	9	8.4
6	W. Va. Shale.....	19.7	866.0	675.0	748.0	5.4	10.9	455.0	356.0	407.0	10	6.4
7	Canton Shale.....	20.2	710.0	557.0	636.0	5.6	12.5	448.0	360.0	403.0	11	6.1
8	Tenn. Ball.....	34.4	727.0	525.0	633.0	7.4	18.2	536.0	455.0	489.0	6	3.8
9	Kittanning No. 2 Fire Clay	14.2	678.0	564.0	631.0	4.0	12.0	551.0	418.0	476.0	7	7.9
10	Great Beam Ball Clay	35.8	710.0	443.0	565.0	12.2	18.7	536.0	416.0	464.0	8	4.2
11	Florida Kaolin.....	40.8	658.0	472.0	539.0	9.1	20.7	323.0	257.0	286.0	13	6.0
12	Georgia Kaolin (b).....	29.6	576.0	447.0	519.0	5.5	14.8	615.0	513.0	559.0	3	5.1
13	Georgia Kaolin (a).....	27.4	535.0	395.0	455.0	8.0	15.1	466.0	329.0	390.0	12	11.3
14	N. C. Kaolin.....	28.5	403.0	303.0	349.0	6.9	16.6	210.0	131.0	168.0	15	14.1
15	M. G. R. China Clay No. 2.	36.7	258.0	202.0	228.0	7.7	18.3	198.0	156.0	172.0	14	5.3
16	M. W. M. China Clay No. 2	37.6	230.0	179.0	205.0	4.9	19.3	194.0	133.0	164.0	16	10.0
					Average	6.6				Average		7.5

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The specimens for the compression tests consisted of two-inch cubes, molded by hand in brass molds. When dried, in the manner described above, they were surfaced with sand paper and crushed in a hand driven Olsen machine of 10,000 pounds capacity, and reading accurately to 2 pounds.

For the transverse test, bars 1 in. by 1 in. by 6½ in. were made in brass molds. They were tested, with a span of five and a half inches between supports. The steel knife edge at the center had a radius of one-half inch, and the end supports were slightly curved in the direction of their length in order to afford better bearing for bars somewhat warped. The modulus was calculated in the usual manner from the formula:

$$M = \frac{3}{2} \cdot \frac{Fl}{bd^2}$$

where M = modulus of rupture;
F = breaking load;
l = length in inches between supports;
b = breadth, in inches;
d = depth, in inches.

For each test the number of specimens made was 50 for each of the first nine and 20 for the last seven clays, the total number of pieces being about 3800. The results of the work are compiled in Tables I, II, and III.

DISCUSSION OF RESULTS

Tensile Strength. By arbitrarily dividing the clays into four classes, according to their tensile strength, the different types are distributed as shown in Table IV.

It would seem that the addition of standard sand affords a more satisfactory classification than the use of the clay alone. The average percent deviation from the mean value is much more consistent in the sand series, and the average of these averages also is lower for the latter, being 6.1 percent as compared with 8.17 percent. The value of tensile strength tests made upon all clay specimens seems to be questionable; the addition of standard

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TABLE III—TRANSVERSE TESTS

		A—WITHOUT SAND					B—WITH 50 PERCENT STANDARD SAND						
NO.	CLAY	WATER CONTENT PERCENT	MAXIMUM MODULUS	MINIMUM MODULUS	AVERAGE MODULUS	AVERAGE DEVIATION FROM MEAN MODULUS PERCENT	WATER CONTENT PERCENT	MAXIMUM MODULUS	MINIMUM MODULUS	AVERAGE MODULUS	RANK	AVERAGE DEVIATION FROM MEAN MODULUS PERCENT	REMARKS
1	M. & M. Ball No. 1.....	36.6	647.0	468.0	558.0	9.1	19.4	359.0	296.0	330.0	1	5.2	8 bars broken in A
2	Kittanning No. 2 Fire Clay	16.3	580.0	470.0	520.0	4.1	12.0	259.0	192.0	216.0	8	6.6	
3	M. & M. Ball No. 11.....	37.2	612.0	411.0	508.0	12.5	20.6	355.0	284.0	319.0	2	5.4	8 bars broken in A
4	No. 3 Ohio Fire Clay.....	18.3	560.0	412.0	484.0	6.5	11.0	322.0	241.0	280.0	4	7.4	
5	Whitaway Ball.....	35.1	492.0	382.0	438.0	7.4	17.5	342.0	254.0	303.0	3	6.0	
6	W. Va. Shale.....	18.5	475.0	354.0	403.0	6.3	10.9	208.0	157.0	178.0	12	5.4	
7	Tenn. Ball No. 1.....	34.4	414.0	338.0	380.0	5.8	18.2	270.0	219.0	243.0	5	4.7	
8	Great Beam Ball.....	35.8	457.0	287.0	375.0	11.3	18.7	269.0	212.0	242.0	6	5.5	
9	Cleveland Shale.....	19.9	396.0	331.0	363.0	4.2	12.8	273.0	205.0	237.0	7	5.5	
10	Georgia Kaolin (a).....	29.8	378.0	257.0	325.0	8.9	15.1	230.0	191.0	210.0	9	3.9	
11	Canton Shale.....	21.1	363.0	278.0	311.0	5.3	12.5	221.0	183.0	199.0	10	4.8	
12	Georgia Kaolin (b).....	29.6	332.0	165.0	269.0	21.2	14.8	205.0	157.0	182.0	11	5.1	7 bars broken in A
13	Florida Kaolin.....	40.8	268.0	207.0	239.0	6.0	20.7	134.0	107.0	122.0	13	5.7	
14	N. C. Kaolin.....	31.8	197.0	131.0	166.0	8.7	16.6	97.0	70.0	82.0	14	6.8	
15	M. G. R. China Clay No. 2.	36.7	115.0	89.0	98.0	6.7	18.3	59.0	44.0	53.0	16	6.9	
16	M. W. M. China Clay No. 2	37.6	89.0	64.0	74.0	7.6	19.3	61.0	52.0	56.0	15	4.2	
			Average			7.9			Average			5.5	

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TABLE IV—TENSILE STRENGTH

	BALL CLAYS	PLASTIC FIRE CLAYS	SHALES	PLASTIC KAOLINS	PRIMARY KAOLINS
Without Sand					
A (200-150 lbs. per sq. in.)	3	1	1	..	..
B (150-100 lbs.)	2	..	2	3	..
C (100-50 lbs.)	..	..	..	..	1
D (50 lbs.)	..	..	..	..	2
With Sand					
A (200-150 lbs. per sq. in.)	3	1	..	..	..
B (150-100 lbs.)	2	1	2	1	..
C (100-50 lbs.)	..	..	1	2	..
D (50-0 lbs.)	..	..	..	..	3

sand would undoubtedly tend to make them more useful and comparable.

Compression Tests. Again adopting an arbitrary classification embracing four divisions, the clays are found to be distributed as follows:

TABLE V—COMPRESSION TESTS

	BALL CLAYS	PLASTIC FIRE CLAYS	SHALES	PLASTIC KAOLINS	PRIMARY KAOLINS
Without Sand					
A (1200-900 lbs. per sq. in.)	2	1	..	..	..
B (900-600 lbs.)	2	1	3	..	..
C (600-400 lbs.)	1	..	..	3	..
D (400-0 lbs.)	..	..	..	..	3
With Sand					
A (800-600 lbs.)	2	..	..	..	..
B (600-400 lbs.)	3	2	3	1	..
C (400-200 lbs.)	..	..	..	2	..
D 200-0 lbs.)	..	..	..	..	3

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From this grouping it follows again that the sand mixtures prove much more consistent than the all-clay specimens. The latter, however, show slightly better agreement among themselves as is shown by the lower average percent deviation from the mean, which is 6.6 percent, as compared with 7.5 percent for the sand series.

Transverse Tests. Again adopting an arbitrary classification of the divisions the clays are found to be distributed as follows:

TABLE VI—TRANSVERSE TESTS

	BALL CLAYS	PLASTIC FIRE CLAYS	SHALES	PLASTIC KAOLINS	PRIMARY KAOLINS
Without Sand					
A (600-500 lbs.) per sq. in.)	2	1	..	..	..
B (500-350 lbs.)	3	1	2	..	..
C (350-200 lbs.)	..	..	1	3	..
D (200-0 lbs.)	..	..	..	..	3
With Sand					
A (350-275 lbs.)	3	1	..	..	..
B (275-200 lbs.)	2	1	1	1	..
C (200-100 lbs.)	..	..	2	2	..
D (100-0 lbs.)	..	..	..	..	3

It seems that the transverse test offers a more satisfactory method for comparison than either of the preceding ones, at least from the experimental standpoint. The average percent of deviation from the mean is also less in this case (using clay-sand specimens). The recommendations of previous workers, concerning the advantage of this form of tests, are hence confirmed. All of the tests upon the dried material are very unsatisfactory, when used as an indirect means of measuring plasticity. On the other hand, they may become of value in the comparison of clays of the same kind, as a check upon different shipments.

The compression test proved especially disappointing, and shows the greatest variation from the average ranking of the

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different clays. The tests with sand were more consistent in this test, than those without sand.

The average ranking of the clays based on all the tests is in the following order:

TABLE VII

CLAY	RANK
M. & M. ball clay No. 1	1.0
M. & M. ball clay No. 11	3.0
Whitaway ball clay	3.3
Ohio No. 3 fire clay	3.3
Kittanning fire clay	6.2
Tennessee ball clay No. 1	7.0
Cleveland shale	7.5
Great Beam ball clay	7.6
W. Va. shale	8.0
Canton shale	9.5
Georgia kaolin (a)	9.8
Georgia kaolin (b)	10.0
Florida kaolin	12.5
North Carolina kaolin	14.0
M. G. R. china clay No. 2	15.0
M. W. M. china clay	15.5

This rating indicates the remarkable strength of the M. & M. ball clay which seems to be in a class of its own. An interesting fact is the close approach of the No. 3 Ohio fire clay to the ball clay basis. A distinct gap seems to occur between the first four and the succeeding clays. Among the next six clays we find included, shales, a plastic fire clay and ball clays. This group is followed by the three plastic kaolins and finally by the primary kaolins.

Conclusions. 1. In all tests of this kind, the variations from the average are so great that no meaning can be attached to the results, unless at least 20 specimens have been broken.

2. The tests with the use of standard sand emphasize the bonding power of the clays, and hence are not comparable with those without sand. Thus a shale may rank high in strength, but owing to its low bonding power, this rating will be reduced

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markedly upon the addition of sand. Wherever the bonding power of the clay is an important requisite, the sand tests should prove of greater value than those of the unmixed material. This applies particularly to ball clays and the plastic fire clays. As a rule, the clay-sand mixtures are more apt to be more consistent than the clay alone, provided the mixing of the materials is accomplished thoroughly. The drying difficulties are obviously greatly reduced.

3. In rating the clays with reference to their general plastic character, the transverse test with sand stands highest, followed by the tensile test, with sand. The same statement is true also with reference to the mean deviation from the average result.

4. Any strength test of clay in the dried state can constitute, at best, but a rough, indirect attempt of estimating plasticity, and fails in differentiating between the various kinds and degrees of plasticity. On the other hand, such determinations have a direct practical value in connection with the drying of clays and the bonding power as shown under heading 2.

DISCUSSION

Mr. Parmelee: What is the tensile strength of the Edgars Florida clay?

Mr. Howat: Florida clay?

Mr. Parmelee: Yes, what is its ordinary tensile strength test?

Mr. Howat: As a maximum 121, as a minimum 110, and as an average 104 pounds per square inch.

Mr. Parmelee: The results that have been published vary anywhere between 130 and 90. My own experience is that it is approximately 90 pounds per square inch.

Mr. Howat: We found it to be about 104 pounds.

Mr. Lovejoy: Where was the No. 2 Ohio fire clay from?

Mr. Howat: It is the Aultman clay.

Mr. F. R. Allen: How does the tensile strength of the cross-breaking test compare with the straight tensile strength? Is there any proportional relation between them?

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Mr. Howat: The relation is shown in the table. For instance Tenn. ball clay No. 1 was the sixth in rank in tensile strength and the fifth in transverse; Canton shale was tenth in both.

Mr. Allen: How do the values compare? Do you get a greater strength from the transverse than from the tensile strength?

Mr. Howat: The transverse test is expressed as a modulus.

Mr. Allen: How does your modulus compare with the tensile strengths? Do you find them of the same order?

Mr. Howat: The highest is the cross-breaking strength. For instance, in the M. & M. ball clay, the tensile strength is 110 pounds per square inch, and the cross-breaking strength is 558.

Mr. Hice: I should like to ask whether it is the Clarion clay or the lower Kittanning. This is a very indefinite proposition. They generally work in Clarion.

Mr. Howat: I think it is Clarion.

Mr. Hice: Most of the work at Kittanning is in the Clarion.

Mr. Howat: It came from McNees.

Mr. Hice: The McNees people are now working the Clarion.

Mr. Lovejoy: My question about No. 3 fire clay was along the same line, there are many clays being used as that, which are not No. 3 at all.

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NOTES ON THE DEVELOPMENT OF THE RUBY COLOR IN GLASS

BY A. E. WILLIAMS

The term "ruby glass" is applied to red glass colored by the use of copper, gold, selenium and in some cases, flowers of sulphur, the color varying considerably in intensity and shade. In case of copper, the color varies from amber to various shades of reds to brown and to opaque black. With gold the red has a rose tint, and selenium ruby seems to be a brighter red of varying intensities. The red from sulphur is rather unreliable, in that a uniform color is hard to obtain, and therefore only used for lower grades of glass.

Copper and gold reds are said to be due to the metals in suspension as colloids.

V. Pöschl[1] describes the preparation of Purple of Cassius from gold, and shows that the red or the purple gold-hydrosol may be obtained, depending upon the proper electrolyte present.

Paal's[2] process for the preparation of colloidal solutions shows that a red or blue hydro-sol of copper is obtained, depending upon the properties of the solutions.

In G. Bredig's[3] method of producing colloids electrolytically, he obtained finely divided metallic gold, dark purple in color, when the arc takes place under distilled water. If a trace of caustic soda is added, deep red color is obtained.

That copper and gold are in the same condition in glass as in solutions is proven by the use of the ultra-microscope.

Zsigmondy[4] says that ruby glass will become red, or remain colorless upon slow cooling according to its quality. It will always remain colorless on chilling, the normal red color generally being brought out upon reheating to the softening point; (high lead glasses show yellow or brown instead of red). The coloring is due to the gold, which is at first homogeneously dissolved in

[1] V. Poschl, *Chemistry of Colloids*, p. 55.
[2] Ibid, p. 66.
[3] Ibid, p. 67.

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the glass, later separating out in the form of ultra-microscopic particles which reflect green light.

He compares this phenomenon with devitrification, and refers to Tammann's[5] work on devitrification. Tammann shows that the speed of crystallization, and the ability to crystallize increase with diminishing temperature from the melting point and then decrease again, while viscosity steadily increases. Zsigmondy applies Tammann's results to ruby glass in this manner:

"Ruby glass is worked several hundred degrees lower than its melting temperature. At the working temperature, conceive it as a super-saturated crystalloid solution of metallic gold and the smallest amicroscopic particles to be centers of crystallization, it will at once be seen why ruby glass sometimes remains colorless upon simple cooling. In this case the optimum temperature for spontaneous crystallization is so low that the glass is very viscous and the speed of crystallization reduced to a minimum. If by reheating, the glass acquires a certain mobility, the gold separates out upon the nuclei present which by growth become sub-microns, visible in the ultra-apparatus and turning the glass red or darker."

V. Pöschl[6] says that gold ruby is obtained by an addition of gold chloride to the glass melt from which particles of gold separate out, when the mass is quickly cooled. These particles, however, have the magnitude of amicrons, so that the glass appears colorless. By heating anew until the glass becomes soft, the particles grow until they attain the size of ultra-microns, to which the cause of the red color is traced. The preparation of copper ruby glass is performed by an analogous method.

Copper ruby has, in the past, been made by a process known as flashing. This process is described somewhat as follows by Rosenhain:[7]

"Flashing glass is the process of placing a very thin layer of colored glass on the surface of a more or less colorless glass of usual thickness. This is generally accomplished by taking a small gathering of the colored glass on the pipe, and the remaining gathering for the piece to be made from the colorless glass pot. When this glass is blown, the ruby glass lies in a thin layer over the inner surface of the cylinder. The special skill required is in blowing this layer to a uniform thickness to obtain a uniform color."

[4] Zsigmondy, *Colloids and the ultra-microscope*, p. 165.
[5] Tammann, *Zeit. for Electro-chemi*, 1904, Vol. 10, p. 532.
[6] Ibid I, p. 103.
[7] Walter Rosenhain, *Glass Manufacture*.

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The necessity of flashing is due to the density of the color. Copper colors are so dense that many glasses are opaque when over 3 m.m. thick, the color depending upon the composition and rate of cooling. However, it is posible to control the density of the color somewhat in the flashed ruby glass by carefully controlling the temperature of working the glass and rate of cooling in the molds.

These factors must be controlled very carefully in practice to produce uniform results. If these glasses are cooled very quickly, as for instance, chilling in water or rolling very thin (2 m.m. thick) on an iron plate, the red color will not develop, or at least shows only in scattered streaks. By reheating at definite temperatures, the color may be obtained in varying degrees of intensity from amber to opaque black, depending upon the temperature to which the glass is reheated. Thus it will be seen that the temperature and rate of cooling must be constant, to produce a uniform shade of red when this color is developed during blowing.

At the present time, however, copper ruby glass is being made in which the color does not come out in the pressing or working, but is brought out later by reheating. The density of the color in this glass is very much less than the flashed ruby glass, and pieces of greater thickness can be easily made. The color ranges from a light amber through reds to a dense opaque black, with an increasing temperature.

Available literature consulted on the subject gave no complete or definite methods for working ruby glass, but emphasized the necessity for care.

The following are some formulae and directions obtained:

Gerner,[8] gives a history of copper ruby glass and a number of mixes with methods of handling. The following are two of the batches given by him:

[8] Gerner, "*Glas*," p. 195.

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GERMAN COPPER GLASS

100.0	Sand
25.0	Potash
17.0	Borax
2.5	Cu_2O
5.0	SnO_2
0.2	Fe_2O_3
2.5	MnO_2
0.5	Bone ash

Calculated Formula[9]

$$\left.\begin{array}{l} 0.200\ PbO \\ 0.390\ K_2O \\ 0.120\ Na_2O \\ 0.095\ CuO \\ 0.079\ MnO \\ 0.014\ CaO \end{array}\right\} \left.\begin{array}{l} 0.0060\ Fe_2O_3 \\ 0.2500\ B_2O_3 \\ 0.0044\ P_2O_5 \end{array}\right\} \begin{array}{l} 4.36\ SiO_2 \\ 0.09\ SnO_2 \end{array}$$

FRENCH COPPER GLASS

$$\left.\begin{array}{r} 100\ SiO_2 \\ 50\ Pb_3O_4 \\ 25\ K_2CO_3 \\ 5\ NaNO_3 \end{array}\right\}$$

This batch is fused, chilled, dried, ground and mixed with 1 Cu_2O, 1.5 SnO_2, 5 cream of tartar. This is melted and blasted one hour during melt.

Calculated Formula

$$\left.\begin{array}{l} 0.534\ PbO \\ 0.346\ K_2O \\ 0.074\ Na_2O \\ 0.046\ CuO \end{array}\right\} \begin{array}{l} 3.900\ SiO_2 \\ 0.034\ SnO_2 \end{array}$$

Notes on ruby glass from Sprechsaal[10] give the following by translation:

"In the manufacture of ruby glass it is not in the field of the furnace man to control the color. Repeated fusion and cooling makes the best color, and the color does not depend as much upon the percent of coloring oxide in the mix as upon the temperature of the glass while working, the rate of fusion and rate of cooling the finished piece." The following batch is given:

[9] The empirical formulae of all glasses given in the following work were calculated by the writer.

[10] *Sprechsaal*, Feb. 6, 1913, p. 92.

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	LIGHT RED	DARK RED
Sand	100.0 kg.	100.0 kg.
Soda ash	16.0 kg.	16.0 kg.
Potash	16.0 kg.	16.0 kg.
Borax	4.0 kg.	6.0 kg.
Whiting	10.0 kg.	12.0 kg.
Witherite	10.0 kg.	10.0 kg.
Cu_2O	2.0 kg.	4.0 kg.
SnO_2	2.0 kg.	4.0 kg.
Fe_2O_3	0.5 kg.	1.0 kg.
Cream of tartar	0.8 kg.	1.3 kg.

Calculated Molecular Formula

$$\left.\begin{array}{l} 0.385\ Na_2O \\ 0.210\ K_2O \\ 0.222\ CaO \\ 0.110\ BaO \\ 0.064\ CuO \end{array}\right\} \left.\begin{array}{l} 0.0066\ Fe_2O_3 \\ 0.0660\ B_2O_3 \end{array}\right\} \begin{array}{l} 3.63\ SiO_2 \\ 0.03\ SnO_2 \end{array}$$

"The manufacture of ruby glass demands great care and practice in working. This is especially so with pressed glass. The raw batch should be put into a preheated pot and melted six hours. The melt is blasted several times and poured into cold water for remelting and refining. If the pressed pieces are not colored enough they can be reheated. The mold must not be too hot to allow the glass to cool too slowly, or too cold to chill and cause the pieces to crack. The following batch is also given:"[11]

Sand	100.0 kg.
Potash	25.0 kg.
Red lead	25.0 kg.
Borax	10.0 kg.
Soda	5.0 kg.
Cu_2O	3.5 kg.
SnO_2	2.0 kg.
Fe_2O_3	0.5 kg.
MnO_2	0.5 kg.
Cullet	25.0 kg.
Cream of tartar	0.5 kg.

[11] Ibid 10, p. 92.

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Calculated Molecular Formula

$$\left.\begin{array}{l} 0.2020\ K_2O \\ 0.6230\ PbO \\ 0.1010\ Na_2O \\ 0.0668\ CuO \\ 0.0079\ MnO_2 \end{array}\right\} \left.\begin{array}{l} 0.00418\ Fe_2O_3 \\ 0.07250\ B_2O_3 \end{array}\right\} \begin{array}{l} 2.310\ SiO_2 \\ 0.018\ SnO_2 \end{array}$$

Rudolf Hohlbaum[12] says that red colors may be obtained by the use of Cu_2O, selenium, sulphur and gold, but is most often obtained from Cu_2O. He gives the following batch for a copper ruby:

100.0	SiO_2	
34.0	K_2CO_3	
16.0	$CaCO_3$	K_2CO_3=80 to 85 percent pure
0.6	Cu_2O	
2.0	SnO_2	

Calculated Formula

$$\left.\begin{array}{l} 0.536\ K_2O \\ 0.440\ CaO \\ 0.023\ CuO \end{array}\right\} \begin{array}{l} 4.570\ SiO_2 \\ 0.041\ SnO_2 \end{array}$$

Hohlbaum says:

"Concerning the mixing of the Cu_2O, I wish to remark that it is possible to obtain the ruby color with 0.4 percent Cu_2O, also with 0.8 percent. However, with 0.8 percent of the batch as Cu_2O the color is so dense that large masses are not workable. As such a small quantity of Cu_2O is needed to make ruby, it is mixed best by using 0.8 percent Cu_2O and SnO with half the batch of glass. When the glass is ready to blast then mix the batch containing 0.8 percent Cu_2O with an equal batch of crystal glass, and a 0.4 percent Cu_2O batch is obtained which gives a weaker color. It is best to employ SnO as a reducing agent to insure the obtaining of a ruby color, and one finds from practical experience that the mix must contain less than double the quantity of Cu_2O as SnO. If this is not sufficient reducing agent, cream of tartar may be used in quantities to satisfy all conditions. Iron scale may also be used as a reducing agent but the pure ruby color is then changed."

[12] R. Hohlbaum, *Seitgewasse Herstellung Bearbeitung und Verzierung des Feinern Holglases*, p. 125.

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Hohlbaum[13] gives the following batch for a gold ruby:

Rose Color

Sand	100.0 kg.
Potash	34.0 kg.
Calcium carbonate	17.0 kg.
Gold	16.0 gms.

Gold must be brought into the mix in a very finely separted form, best in solution or as Purple of Cassius.

To get the gold in solution, it must be cut into small pieces and dissolved with aqua regia. The gold solution is poured on part of the mix, and this mixed with the balance of the batch.

In the heat of the oven, the decomposition of the gold chloride takes place so rapidly, that a portion of the gold chloride is carried away undecomposed. There is, therefore, not so much gold dissolved in the glass as is introduced, and the color is much weaker than it would be, if all the gold were dissolved. It is, of course, reasonable for one to try and reduce the vaporization of the gold chloride as much as possible. This may be done by pouring the gold chloride on 1 kgm. of sand and evaporating to dryness. Then mix this well with half of the batch, or use gold purple in the same manner.

According to Hohlbaum's experience, either phosphoric acid or barium work favorably in the making of gold ruby, causing the gold to separate out more rapidly. Without either, the ruby is too light. A batch for making a rose glass with a violet tinge with the use of barium is given.

Rose Glass with Barium

Sand	100.0 kgm.
$BaCO_3$	16.0 kgm.
95 percent soda, Na_2CO_3	43.0 kgm.
Gold	12.0 gms.

Selenium Ruby, Light and Rose Colored

Arsenic	200.0 gms.
Sand	100.0 kgm.
Potash, 80-85 percent	34.0 kgm.
$CaCO_3$	17.0 kgm.
Selenium nitrate	120.0 gms.

[13] Ibid 12, p. 126.

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In the reds with sulphur, one should not use the alkali sulphates, but only sulphur with charcoal as a reducing agent. The charcoal keeps the sulphur from combining with the soda and potash. In sulphur ruby, a great part of the sulphur vaporizes in the working. The melting glass foams vigorously, and therefore one should fill the pot only half full at first, and after the batch reaches quiet fusion, put in the second half.

Sulphur ruby is hard to make in uniform colors, and darkens in the muffle. It is not used for making higher grades of glass. Two batches for sulphur ruby are given:

	No. 1	No. 2
Sand	100.0 kgm.	100.0 kgm.
Soda	45.0 kgm.	45.0 kgm.
$CaCO_3$	20.0 kgm.	20.0 kgm.
Flowers of sulphur	7.0 kgm.	10.0 kgm.
Antimony sulphate	5.0 kgm.	
Charcoal	2.0 kgm.	

EXPERIMENTAL DATA BY WRITER

The foregoing typical batches for ruby glass are but a few of a large number given in the literature pertaining to glass making. An examination of these shows a wide variation in composition, but all agree in that they are high in silica and contain tin. In copper ruby, the amounts of copper and tin vary widely in their ratios to each other. These copper rubies are probably used in the manufacture of flashed glass.

In the beginning of the following experimental work, samples of commercial copper ruby, both the quick-cooled colorless and ruby colored were obtained. The uncolored sample was broken into fragments, and different fragments were heated to different temperatures for various lengths of time. A small Hoskins electric furnace was used, and temperatures were read with a Leeds Northrup potentiometer, using a platinum, platinum-rhodium thermocouple.

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The following results were obtained:

TABLES

PIECE NO.	MAXIMUM TEMPERATURE	TIME HELD AT MAX. TEMP.	REMARKS
	°C	*minutes*	
1	500	30	No change in color
2	500	60	No change in color
3	550	30	No change in color
4	550	60	No change in color
5	575	1	No change in color
6	575	30	No change in color
7	600	1	Very light amber
8	600	15	Very light amber
9	600	30	Bright amber, slightly darker than No. 8
10	600	60	Bright amber, same as No. 9
11	650	1	Bright amber, same as No. 9
12	650	30	Deep ruby, edges slightly softened
13	650	60	Same as No. 12, edges slightly softened
14	675	15	Same as No. 12, edges slightly softened
15	675	30	Same as No. 12, edges slightly softened
16	675	60	Darker than No. 15, edges slightly softened
17	700	1	Same as No. 10, edges slightly softened
18	700	30	Dark red, edges slightly softened
19	900	30	Grayish purple, opaque, softened out of shape

The rate of increase of temperature was a constant factor in all of these tests, as follows: ten minutes from room temperature to 300°C; 300°C to 500°C at rate of 50° per minute; 500°C to maximum temperature at a rate of 25° per minute.

The results seem to show that the color at any definite temperature is practically constant, and that the color change at that temperature is apparently instantaneous. However, time is

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required for the temperature to even up through-out the thickness of the piece.

It will be noticed that the glass shows signs of softening at that temperature at which the strong color develops. This is probably the softening point Zsigmondy[14] refers to in the article previously quoted. It is observed that there is little or no apparent change in color brought out between 650° and 675°, giving a safe range for an annealing oven.

Most of the glass formulas observed were high in lead and in silica. Accordingly the following formula was selected, it being the upper silica limit for most glasses:

$$\left.\begin{array}{l} 0.5\ PbO \\ 0.5\ Na_2O \end{array}\right\}\ 3\ SiO_2$$

In order to determine a suitable method of working, several small batches of this glass were fused. The method adopted was as follows:

The glass was fused in Battersea crucibles in a small pot furnace using gas and compressed air. The temperature range required for firing and to make the glass liquid enough for pouring, was between 1480°C and 1520°C. One-half hour was taken for complete fusion of the lead glasses and one hour for the leadless glasses.

Not much trouble was experienced in reducing the copper oxide and preventing oxidation. Although a slight reducing flame was used, the presence of cream of tartar (about ½ percent) seemed to make reduction certain, if the time of heating was not too long.

When fusion was complete. the glass was poured on a heavy cast iron plate 1 in. thick, and then rolled to a thickness varying from 2 to 5 m.m. The thinner portions usually cooled colorless, and the color developed in the thicker, slower cooled portions, i. e. turning red or opaque brown or black.

[14] Ibid 4.

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FORMULAS

MATERIAL	SERIES A GLASS NO.							SERIES A_1 GLASS NO.			
	1	2	3	4	5	6	7	1	2	3	4
Na_2O	0.50	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
PbO	0.50	0.500	0.500	0.500	0.500	0.500	0.500	0.300	0.300	0.300	0.300
CaO	....	.....	.....	.....	.....	.....	.....	0.200	0.200	0.200	0.200
SiO_2	3.00	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
CuO	0.04	0.004	0.004	0.002	0.001	0.0005	.....	0.004	0.003	0.002	0.002
SnO_2	0.04	0.004	0.010	0.007	0.007	0.007	0.007	0.010	0.010	0.010	0.007
Cream of tartar, percent	0.50	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

BATCH WEIGHTS

	SERIES A							SERIES A_1			
Na_2CO_3	35.3	35.30	35.30	35.300	35.300	35.300	35.300	35.30	35.30	35.30	35.300
Pb_3O_4	57.0	57.00	57.00	57.000	57.000	57.000	57.000	.....	.....	.....	.....
White lead	....	.....	.....	.....	.....	.....	.....	34.30	34.30	34.30	34.300
$CaCO_3$	....	.....	.....	.....	.....	.....	.....	10.00	10.00	10.00	10.300
Flint	90.0	90.00	90.00	90.000	90.000	90.000	90.000	90.00	90.00	90.00	90.000
Cu_2O	1.4	0.14	0.14	0.070	0.035	0.018	0.000	0.14	0.10	0.07	0.070
SnO_2	3.0	0.30	0.75	0.052	0.052	0.052	0.052	0.75	0.75	0.75	0.052
Cream of tartar	1.0	1.00	1.00	1.000	1.000	1.000	1.000	1.00	1.00	1.00	1.000

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SERIES A

Glass batches were then made corresponding to the formulas given in Series A.

The following results were obtained:

Number 1—Colored out very dense opaque grayish-brown color.

Number 2—(Decreasing the coloring agent.) This poured well, and cooled practically colorless at 5 m.m. thick. Softened out of shape at 675°C. and colored out, streaked with reddish color. At 700°C. it became dark brown, opaque and still streaked, very soft.

Number 3—(Increasing tin to harden.). This poured well and was colorless except for a pale greenish-yellow color at 5 m.m. thick.

Heated to 480°C, gives amber color,
Heated to 525°C, gives deep red color,
Heated to 700°C, softened out of shape giving a dense, brown opaque glass. Color change very rapid.

Number 4—(Decreasing the Cu_2O to reduce intensity of color). Color developed darker than No. 3 in pouring, having a greenish cast. Heated to 600°C, its color was deep opaque, and nearly black, amber at 550°C., and brown at 575°C.

Number 5—Developed a rather intense brown color while pouring. Thin colorless sections gave a deep greenish brown at 550°C. and a dense opaque black at 600°C.

Number 6—(Still reducing amount of coloring matter). This glass poured clear and colorless. On reheating, it changed to opaque black from 550°C. to 600°C. Color change very rapid.

Number 7—(Coloring matter left out to test purity of materials for iron). This glass on reheating at various temperatures gave no change in color.

The conclusions from this series of glasses, (excluding No. 1)[15] are:

(1) Low amounts of copper seemed to increase the density

[15] This glass was not melted well enough to judge results.

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or opacity of the color, and decrease the signs of red, giving greenish browns.

(2) An increase in the tin in No. 3 stopped the streakiness shown in No. 2.

(3) Glass No. 3 was the best glass in series A, giving a colorless glass when poured and cooled quickly. Reheating showed shades of good red at various temperatures. However, the color change is so rapid, it would be difficult to control uniformity of color.

SERIES A1

Series A_1 was constructed in order to obtain harder glasses than those in series A, by replacing PbO with CaO so as to raise their temperatures of softening, and to determine how this affects the range of color change.

Glass No. 1 of this series showed a dark brandy color on pouring, coloring out quicker than No. 3 series A, which contained the same equivalents of Cu and Sn. This glass did not soften out of shape on reheating at 700°C., as did glass No. 3, series A, but gave a dense opaque color. If it could be handled, without coloring in pressing, this glass gives a good transparent red at 5 m.m. thick, upon reheating to the proper temperature.

Glasses Nos. 2 and 3 (reducing Cu_2O). Colored out quite dense, on pouring becoming nearly opaque. When reheated above 600°C. the glass turned a deep opaque purple.

Glass No. 4 (reducing SnO_2). This glass seemed to color out as rapidly as Nos. 2 and 3.

The conclusion which may be drawn from this series is that the rapidity of precipitation, or growth of color is increased, instead of decreased, as would be expected by hardening the glass.

SERIES B

The basal formula for this series is one of the published formulas given in Sprechsaal.[16] It is a high lead, low silica glass, containing some borax and is a much softer glass than series A and A1.

[16] Ibid 10.

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FORMULAS

Series B

GLASS NO.	Na_2O	PbO	K_2O	SiO_2	CuO	SnO_2	MnO_2	Fe_2O_3	B_2O_3	CREAM OF TARTAR
										percent
1	0.101	0.623	0.202	2.31	0.0668	0.018	0.0079	0.0042	0.0725	0.5
2	0.102	0.627	0.202	2.33	0.0670	0.018	.....	0.0042	0.0730	0.5
3	0.101	0.623	0.202	2.31	0.0668	0.018	0.0079	.....	0.0725	0.5
4	0.102	0.627	0.202	2.33	0.0670	0.018	.....	.....	0.0730	0.5
5	0.102	0.627	0.202	2.33	0.0670	.....	.....	.....	0.0730	0.5
6	0.102	0.627	0.202	2.33	0.0670	.....	.....	0.0042	0.0730	0.5
7	0.101	0.623	0.202	2.31	0.0668	.....	0.0079	0.0042	0.0730	0.5
8	0.119	0.627	0.202	2.33	0.0500	0.018	.....	.....	0.0730	0.5
9	0.129	0.627	0.202	2.33	0.0400	0.018	.....	.....	0.0730	0.5
10	0.139	0.627	0.202	2.33	0.0300	0.018	.....	.....	0.0730	0.5
11	0.098	0.627	0.202	2.33	0.0710	0.018	.....	.....	0.0730	0.5
12	0.092	0.627	0.202	2.33	0.0770	0.018	.....	.....	0.0730	0.5
13	0.102	0.627	0.202	2.33	0.0670	0.023	.....	.....	0.0730	0.5
14	0.102	0.627	0.202	2.33	0.0670	0.067	.....	.....	0.0730	0.5
15	0.102	0.627	0.202	2.33	0.0670	0.134	.....	.....	0.0730	0.5

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The results showed this very markedly. The fusions, made at the same temperature range 1480°C and 1520°C, were more fluid and poured easier.

Numbers 1, 2, 3 and 4 developed deep opaque glasses when poured 4 to 5 m.m. thick. The thinner portions, however, increased in degree of transparency to about 2 m.m. at which thickness the glasses cooled colorless, but of course very brittle. Upon reheating, the colorless pieces of these four glasses colored to about the same color density when heated to the same temperature. At 500°C, they showed an amber color changing to a light red at 525°C., and to a ruby color at 550°C., becoming opaque at 600°C. Leaving out the iron, or manganese or both, (especially the latter), seemed to improve the quality of the red and to give a less dense color. This type of glass gives a much better red color than any of series A, but it is impossible to work with sections as thick as commercial glass pieces would be made and still obtain a transparent color. However, it would work as a ruby glass in making flashed articles and give a good color. Manganese dioxide and Fe_2O_3 are detrimental rather than helpful in obtaining good colors.

In series B, Numbers 5, 6 and 7 (in which SnO_2 is absent), the glasses were more opaque in all cases. Number 7 colors out even in the thin sections to a dense black.

In glasses Nos. 8, 9, 10, 11 and 12, the tin was kept constant and the copper varied. In all cases the tendency was to increase opacity and the rapidity in which the color appeared on pouring.

In glasses Nos. 13, 14 and 15, in which the tin was increased, no beneficial results were obtained, since these glasses were more opaque than the preceding ones in the group.

The ruby color in glasses as soft, and as low in SiO_2 as the members of this group cannot be controlled. However, when B1 and B2 were melted, quenched in water and remelted, there was an improvement, since all signs of streakiness disappeared, and the color became very uniform on reheating.

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BATCH WEIGHT

Series B

GLASS NO.	FLINT	POTASH	WHITE LEAD	BORAX	SODA ASH	Cu_2O	SnO_2	Fe_2O_3	MnO_2	CREAM OF TARTAR
										percent
1	100	26.0	30	10	13.2	3.50	2.00	0.5	0.5	1.0
2	100	26.0	30	10	13.2	3.50	2.00	0.5	...	1.0
3	100	26.0	30	10	13.2	3.50	2.00	...	0.5	1.0
4	100	26.0	30	10	13.2	3.50	2.00	...	...	1.0
5	100	26.0	30	10	13.2	3.50	....	...	...	1.0
6	100	26.0	30	10	13.2	3.50	....	0.5	...	1.0
7	100	26.0	30	10	13.2	3.50	....	0.5	0.5	1.0
8	100	26.0	30	10	17.2	2.60	2.00	...	...	1.0
9	100	26.0	30	10	18.8	2.10	2.00	...	...	1.0
10	100	26.0	30	10	20.6	1.56	2.00	...	...	1.0
11	100	26.0	30	10	12.4	3.70	2.00	...	...	1.0
12	100	26.0	30	10	11.2	4.03	2.00	...	...	1.0
13	100	26.0	30	10	13.2	3.40	2.55	...	...	1.0
14	100	26.0	30	10	13.2	3.40	7.45	...	...	1.0
15	100	26.0	30	10	13.2	3.40	14.90	...	...	1.0

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The basis of this series obtained from Hohlbaum[17] is entirely different than series B. It is a lime-potash, high silica, leadless glass, with high tin, therefore, a comparatively refractory and viscous glass at low temperatures. One hour was taken for fusion.

Hohlbaum's batch calls for SnO as the reducing agent, cream of tartar being added as a precaution to insure sufficient reduction. Number C-I was first made by substitution of SnO_2 for SnO, and leaving out the cream of tartar. An oxidized clear colorless glass was the result, giving no color change when reheated beyond the softening point.

Number C-I was again made using SnO_2 and 0.5 percent cream of tartar. This glass was exceedingly viscous and quickly cooled below the point of easy pouring. Upon pouring and rolling, (although taking a little more time), no color change took place, the glass remaining clear and colorless.

Upon reheating, no color change took place until

800°C. was reached, when a light amber color was obtained,

850°C. gave a pale reddish brown,

900°C. gave a light brown,

1000°C. softened with an opaque brown color.

The red color was not good in this glass and it seemed to be entirely too refractory.

Series C, No. 2. (Reducing SiO_2 to soften). This showed an improvement in the working qualities with no tendency to color out on pouring.

Reheating this glass gave the following results:

800°C. a distinct light red,

850°C. a good ruby color,

900°C. a deep dark red nearly opaque when 4 m.m. thick.

Series C, No. 3 (reducing SiO_2 still further) gave a fusion which poured colorless and flowed freely. Reheated to 850° it showed a reddish brown, slightly streaked. 900° showed a distinct deep brown.

[17] Ibid 11, p. 125.

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FORMULAS
Series C

GLASS NO.	SiO_2	K_2O	CaO	CuO	SnO_2	PbO	Na_2O	B_2O_3	CREAM OF TARTAR
1	4.57	0.536	0.440	0.023	0.041	.....	.....	.....	0.5
2	4.00	0.536	0.440	0.023	0.041	.....	.....	.....	0.5
3	3.50	0.536	0.440	0.023	0.041	.....	.....	.....	0.5
4	3.00	0.536	0.440	0.023	0.041	.....	.....	.....	0.5
5	2.75	0.536	0.440	0.023	0.041	.....	.....	.....	0.5
6	4.57	0.536	0.240	0.023	0.041	0.200	.....	.....	0.5
7	4.00	0.536	0.240	0.023	0.041	0.200	.....	.....	0.5
8	4.00	0.536	0.340	0.023	0.041	0.100	.....	.....	0.5
9	4.00	0.536	0.340	0.023	0.041	.....	0.100	0.200	0.5
10	4.00	0.536	0.340	0.023	0.041	.....	0.100	.....	0.5
11	4.57	0.536	0.340	0.023	0.041	0.100	.....	.....	0.5
12	4.57	0.536	0.340	0.023	0.041	.....	0.100	.....	0.5

BATCH WEIGHTS

GLASS NO.	FLINT	POTASH	WHITING	Cu_2O	SnO_2	WHITE LEAD	SODA ASH	BORAX	CREAM OF TARTAR
1	200.0	68.0	32.0	1.2	4.46	....	....	....	2.0
2	175.0	68.0	32.0	1.2	4.46	....	....	....	2.0
3	153.0	68.0	32.0	1.2	4.46	....	....	....	2.0
4	131.0	68.0	32.0	1.2	4.46	....	....	....	2.0
5	120.0	68.0	32.0	1.2	4.46	....	....	....	2.0
6	200.0	68.0	17.4	1.2	4.46	29.4	....	....	2.0
7	175.0	68.0	17.4	1.2	4.46	29.4	....	....	2.0
8	175.0	68.0	25.0	1.2	4.46	15.0	....	....	2.0
9	175.0	68.0	25.0	1.2	4.46	....	....	22.9	2.0
10	175.0	68.0	25.0	1.2	4.46	....	10.4	....	2.0
11	200.0	68.0	25.0	1.2	4.46	15.0	....	....	2.0
12	200.0	68.0	25.0	1.2	4.46	....	10.4	....	2.0

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Series C, No. 4 (less SiO_2 than C3). Poured clear and colorless but when reheated to 850° became more streaked and showed a more decided brown.

Series C, No. 5, poured clear and colorless as the others, but showed brown streaks. When reheated to 800° it showed a very streaked brown color. When the glass was remelted and repoured it gave a very clear glass.

Upon reheating this to 750°C. the color came out a clouded black, increasing in intensity with the reheating temperature.

The foregoing five glasses in group C show that:

(1) Reducing the SiO_2 from 4.57 to 4.0 molecules improved the color in this series. Further reduction, however, changed the color to browns and then blacks, giving about the same range of brown and blacks with 3 SiO_2 as series A gave having 3 SiO_2 and small amounts of copper.

(2) High silica seems necessary in order to develop a good red color. The color change takes place at rather high temperatures for a reheating furnace, and the glass appears to be too viscous for good working properties. Glasses C6, C7 and C8 were made by introducing PbO in place of part of the CaO with the idea of softening and, if possible, still retaining the property of not coloring out on pouring.

C6 and C7 in which 0.2 PbO replaced 0.2 CaO showed a distinct improvement in the working qualities and uniformity of color, although these glasses colored out in the thicker portions during the pouring; C6 to a light red and C7 to a deep ruby. These glasses, however, were transparent to a thickness of 8 m.m. in comparison with series B, which were not transparent in pieces over 2½ m.m. in thickness.

Reheating clear portions of C6 gave a good, deep, ruby color at 650°C., a considerable lowering of the temperature over the leadless glasses for developing color. This glass also has a fairly constant color over a temperature range of 25°C (625° C. to 650°C).

Series C, No. 7 colored out at 570° to the same shade as C6.

Series C, No. 8 (Reducing PbO to 0.1 with 4.00 SiO_2). This glass gave evidences of being harder than the previous glass

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(C7) as the fusion colored out a very little clearer at 6 m.m. thick (similar to C6), and the colorless portions gave a deep clear ruby on reheating to 570°, the same as C7 and about 60° lower than C6. This glass gave the clearest and best red obtained in the foregoing work.

Series C, No. 9 (in which 0.1 PbO was replaced in C8 by 0.1 Na_2O as borax) gave a glass considerably more fusible, and flowed well in pouring. A very streaked, nearly black, color developed in portions over 3 m.m. in thickness on pouring. Thin transparent pieces heated to 750° gave a red color, streaked with opaque black lines. This fusion, therefore, did not give good results. The possibility of spoiling the color by over-heating is ever present. It is possible that less B_2O_3 would give better results, though this was not tried.

Series C, No. 10 (0.1 Na_2O replacing 0.1 CaO). The resulting glass was clear and colorless, showing a very few light red streaks. The working properties of the glass were very good, especially in pouring and cooling.

On heating to 700°C the glass turned a clear light red.
625°C. showed a clear light red.
725°C. showed a clear light red.

The color range of this glass is therefore good.

Series C, No. 11 (0.1 PbO replacing 0.1 CaO and with 4.57 SiO_2). Results from this glass were a failure as the fusion was incomplete and very viscous and colored out a dense opaque black on pouring. If properly fused, better results would no doubt have been obtained.

Series C, No. 12 (0.1 Na_2O replacing 0.1 CaO and with 4.57 SiO_2). This glass gave a very good fusion, but was rather viscous and showed no color on pouring. Heating this glass to 700°C gave an amber colored glass streaked with dark red lines. At 800°C it showed a good even ruby color.

The conclusions from this last series of glasses (C6 to C12) are (1), that soda replacing lime softened the glass without causing the color to come out in cooling. (2) Lead on the other hand caused these glasses to color out rapidly on cooling, but did not make them opaque.

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General Conclusions. The following are general conclusions one may draw from this work regarding the composition of a workable ruby glass. A workable ruby glass is one which will not color out when cooled at the rate obtained in the pressing process, and yet will give a workable range of temperature for reheating to a uniform color at temperatures below 700°.

1st. Highly fluid glasses will color out rapidly, viscous glasses slowly.

2nd. Replacing lime with either lead or soda, increases the rapidity of color development, lead more so than soda.

3d. High SiO_2 is necessary for good color, low SiO_2 gives a tendency towards brown or black, and opacity.

4th. High SiO_2 (4.0 to 4.5 mol.), is necessary to give sufficient viscosity.

5th. With high silica, lime-potash glasses the tendency to streakiness increases. Small amounts of lead reduce streakiness.

6th. The glass giving the best color in series B is No. 4. Glasses Nos. 1, 2, 10 and 12 of Series C, most nearly approached the requirements of a good ruby glass. They could all be poured without the color developing, and on reheating, the color developed at favorable temperatures. Glasses Nos. 6 and 8, Series C gave the most transparent colors.

7th. Iron and manganese are detrimental to a good red color.

8th. Remelting improves the uniformity of the color which indicates that streakiness is due to lack of homogeneity.

9th. Density of color is apparently increased with an increase in temperature. Time is evidently not an important factor in this case.

DISCUSSION

Prof. Silverman: There are a number of points in Mr. Williams' paper about which I wish to inquire. In the first place, he speaks of the coloring out in the high-silica copper rubies. I should like to ask whether Mr. Williams found any direct bearing by the alkali content of the glass. There is a claim

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made at present that a copper ruby can be manufactured, which is a ruby, out of the pot. I believe his views correspond with mine in that the red color produced is due to high alkali in the glass. In other words, the glass colors out while cooling in the mold, or even earlier. Then as to tin as a reducing agent, I can corroborate these statements also, having had the experience that tin alone in connection with copper gives a rich color, while with manganese and iron the color is off. Tin has to be controlled very carefully. If you get below a certain point you obtain a glass which does not color sufficiently; and if you go above you get what is called clouding or a livery color.

I would like to ask, to what Mr. Williams attributes lack of uniformity of color; and whether he feels that a melt over a short duration, like thirty minutes could give a homogeneous glass.

Mr. Williams: To answer the last question first: the uniformity of color in my glasses was not obtained in the first melt. There were signs of streakiness at first, but upon remelting, good clear colors were obtained. It is probably the mechanical handling of the glass, or the duration of the melt which has a tendency to make the glass cloudy or clear.

The first question you asked, regarding the high alkali content, I did not quite understand, however I will make this point, that when I used lead, replacing the alkali, it caused the colors to come out more quickly in the handling. The color was just as good, in fact a little better, but density of color could not be controlled. Lead improved the uniformity of the color but gave a tendency toward opacity. If you do not want the color to come out during pressing, it is necessary to keep away from lead.

Prof. Silverman: I should like to know further, what the object is in trying to prevent the color from coming out during pressing.

Mr. Williams: If you do not prevent it, the different variations in the cooling of the mold would not give the same shading of red in the finished pieces.

Prof. Silverman: But do you not get the same effect by heating to a certain temperature afterwards?

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Mr. Williams: Yes; but can you control the rate of cooling of glass in the mold sufficiently accurately as to give uniformity of color from piece to piece?

Prof. Silverman: I cannot quite see how that has a bearing on the rate of cooling. Suppose your glass does not color out below 700°. You might have a mold anywhere from 400° to 600°, and the fact that you have no color would be no indication that your mold temperature is correct. In other words, you have such a large range below the coloring-out temperature that it does not seem any better indication as to mold temperature, than if you had a glass that colored out, except possibly to tell you that the mold is too hot.

Mr. Williams: My experience with glass that colored out was that glass of various thicknesses was different in shade. The difference in temperature of a mold would influence the color. The coloring out at a definite temperature also depends upon the speed at which a glass cools through the small temperature range of color development. If the glass cools at a high rate of speed through this temperature, the colloidal copper would not come out in large enough particles to show color. If the cooling rate is slower the particles grow of sufficient size to give color.

Mr. Gelstharp: I should like to ask whether that was not sub-oxide of copper.

Mr. Williams: I used cuprous oxide.

Prof. Stull: Perhaps I might throw a little light on Prof. Silverman's question by stating, that among the things Mr. Williams is investigating is a study of the temperatures at which the copper ruby comes out, and the effect of length of time as well as temperature in bringing it out. That is why he is trying to secure colorless glass to begin with.

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A COMPARISON BETWEEN ENGLISH AND AMERICAN GLAZE PRACTICE

BY ERNEST MAYER, BEAVER FALLS, PA.

In about forty years of experimenting in making glaze, it has been my practice to change any glaze mixture I got from reading, or was given to me, into its chemical formula, and while they are made from so many different substances and looked so totally unlike before they were resolved into a formula, yet I was always struck with their great similarity in their final analysis.

You will understand, of course, I am speaking strictly of earthenware (now usually called semi porcelain) as made in England and the United States.

To illustrate the point I want to bring out, I will take three glazes.—the first one being a typical English glaze and one used by a well known firm; the second is a typical American glaze and used by a firm whose ware ranks very high in American manufacture; and the third is taken from Langenbeck's Chemistry of Pottery, page 122, where he says "the best glazes for these wares (earthenware—semi porcelain) approach a formula of the following character." The glaze here referred to is marked No. 3 Langenbeck glaze.

No. I—TYPICAL ENGLISH GLAZE

FRIT		GLAZE		ANALYSIS	
Flint	180	Frit	333	K_2O	1.65
Stone	164	Flint	93	Na_2O	4.11
P. White	164	Stone	214	CaO	6.70
Borax	328	Lead	174	PbO	19.16
Ch. clay	60			MgO	0.07
				Al_2O_3	7.75
	896		814	SiO_2	52.79
				B_2O_3	7.77
					100.00

$$\left.\begin{array}{l} K_2O\ 0.059 \\ Na_2O\ 0.244 \\ CaO\ 0.401 \\ MgO\ 0.006 \\ PbO\ 0.289 \end{array}\right\} Al_2O_3\ 0.254 \left\{\begin{array}{l} SiO_2\ 2.944 \\ B_2O_3\ 0.372 \end{array}\right.$$

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No. II—TYPICAL AMERICAN GLAZE

FRIT		GLAZE		ANALYSIS	
Boracic acid	225	Frit	413	K_2O	6.02
Flint	322	Feldspar	413	CaO	7.33
		White lead	195	PbO	14.21
	547	Paris white	150	ZnO	2.59
		Zinc oxide	30	Al_2O_3	8.61
		China clay	60	SiO_2	51.26
			1261	B_2O_3	9.98
					100.00

$$\left.\begin{array}{l} K_2O\ 0.22 \\ PbO\ 0.22 \\ CaO\ 0.45 \\ ZnO\ 0.11 \end{array}\right\} Al_2O_3\ 0.29 \left\{\begin{array}{l} SiO_2\ 2.93 \\ B_2O_3\ 0.49 \end{array}\right.$$

No. III—LANGENBECK GLAZE

FRIT		GLAZE		ANALYSIS	
Borax	47.8	Frit	70.7	K_2O	3.37
Boracic acid	31.0	Paris white	12.5	Na_2O	2.22
Feldspar	69.6	White lead	32.9	CaO	8.03
Paris white	25.0	China clay	22.7	PbO	15.92
Flint	15.0	Flint	49.5	Al_2O_3	8.78
				SiO_2	51.64
	188.4		188.3	B_2O_3	10.04
					100.00

$$\left.\begin{array}{l} K_2O\ 0.125 \\ Na_2O\ 0.125 \\ CaO\ 0.500 \\ PbO\ 0.250 \end{array}\right\} Al_2O_3\ 0.300 \left\{\begin{array}{l} SiO_2\ 3.00 \\ B_2O_3\ 0.50 \end{array}\right.$$

By a careful study of the above formulas, I claim that they are all identical as far as their final analysis is concerned, and I do not claim for an instant that either the English or American has any superiority one over the other as to their appearance or utility, but what I do claim is that the American glaze is both chemically and economically very wrong, as I expect to show.

First. By making a frit of boracic acid and flint only, we have no chemical union, and after firing the result is a soluble frit, which to say the least, makes it very unsafe to use in a glaze on account of the variable nature of the glaze produced. In my judgment, this is a very serious error.

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Second. It is practically the universal custom in the United States to make all frit in saggers, which is not only done at an enormous expense as fully explained in Vol. IX, *Trans. Amer. Cer. Soc.*, page 195 (Fritting by the Kiln and Sagger Process), but on account of the long duration of the fire twenty-four to thirty times an appreciable percentage of the boracic acid is lost by volatilization, and this brings another uncertain element into the composition of the glaze.

Third. There is another point in American glaze practice that I will call your attention to, viz., the use of oxide of zinc which I have never seen in any glaze (earthenware) mixing either English, German or French. Why it is used, I cannot tell, and never found anyone who could. There is one point about it I do know, however, and that is, it has a very harmful effect on some underglaze colors, particularly greens, which are generally turned into various shades of brown.

When I conceived the idea of writing these notes on the comparison of making glazes in the two countries, I had not the chemical side of the problem in view nearly as much as the economic side.

Recently, our factories have been visited by government experts who have gone through our books and examined all our processes, machinery, etc., and we have heard much talk about "efficiency." I have given my reasons for claiming the American glaze is wrong chemically. I would also state clearly and most emphatically, that it is wrong **economically,** and I will show, why it is wrong economically.

Such a glaze as I have shown to be a typical American glaze requires 1050 lbs. at $0.04¼ per lb.=$44.62 to dip a 15 ft. 6 in. glost kiln; whereas of the typical English glaze it requires 775 lbs. at $0.029=$22.48 to dip a 15 ft. 6 in. glost kiln; saving $22.14.

This saving represents an amount that is equivalent to the value of the fuel required to fire the kiln, and is something that ought to make any man interested in efficiency problems "sit up and take notice."

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I wish to add as a foot-note to the above that in making experimental glazes, I used the following mixture in place of Cornish stone, and in glazes where I have used this mixture and also Cornish stone, I never could see a particle of difference as regards the general appearance, effect on underglaze colors, etc. In place of 100 lbs. of Cornwall stone, I used:

Feldspar	42.84
China clay	26.71
Flint	34.24
	103.79

I am sure it is unnecessary for me to point out that while such a mixture is a perfect substitute for Cornwall stone in a glaze, it is absolutely worthless as a substitute in a body.

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A RATIONAL PIECE WORK METHOD FOR PLACING KILNS

BY J. MINNEMANN

It is the custom among manufacturers of clay products to pay their kiln placers a fixed amount per kiln, regardless of the quantity of ware placed, the man in charge of the kiln setting being expected to see that a fill is always obtained.

It is a well known fact that the average man will not do nearly so much work in a given time when working by the hour as when working by the piece, and neither will the average kiln setter place as much ware per kiln when paid by the kiln as when paid by the amount placed. In a porcelain plant, where the kiln capacity was not equal to the output of the manufacturing departments, an attempt was made to increase the kiln capacity by placing more ware per kiln, the ware in question being porcelain insulators of various sizes and shapes. It was found that while considerable advantage could be had in having saggers of the right size and shape, and in an assortment of ware, still, the amount of ware placed per sagger depended upon the man, as no definite rules could be laid down, owing to the ever changing sizes and shapes of the ware.

In order to get more ware per sagger, it was decided to pay the placers per piece, or rather per cubic inch of space taken up by the given piece, each piece being considered as taking up a space equal to the volume of its circumscribing cylinder.

It is evident that when pieces are nested, the price paid is the same as when they stand separately, thus putting a premium on nesting. The cubical content of each piece is determined, and kept on file in the office. When the count of the ware placed in each kiln is turned in, the number of pieces of each style is multiplied by the cubical content of that style, and the products so obtained are added, giving the total cubical content of the ware placed in that kiln. These figures are in cubic inches, and the price paid the placers is in dollars per million cubic inches, which is divided among the men on the gang.

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It is evident, that it is to the advantage of the placer to get as much ware in each sagger as possible, as it is no more trouble to carry a sagger containing one piece more than one piece less. In this way, the method has the advantage of a bonus system, because every additional piece placed in a sagger is paid for at the same rate as the first, while the work is but little increased. After the system had been installed for several weeks, it was found that the amount of ware per kiln had increased about 20 percent, and the wages of the workmen had increased about 8 percent at the same time. This system has now been in successful operation in this plant for nearly two years, and in that time, the amount of ware per kiln has been continually on the increase, as the workmen became more proficient in getting every sagger filled.

In another plant making similar ware, the kiln setting had been paid for by the hour. Upon adopting this system the kiln capacity was immediately increased 25 percent, giving the workmen an increase of about 12 percent per hour, without increasing the cost per kiln. As an increase in ware per kiln does not increase the firing cost appreciably, it is evident that this is clear gain, besides being a way to increase production with the same equipment.

While in use to his knowledge, only in the electric porcelain business, the writer feels that such a method could be adapted to any plant where the variety of ware is such that the complete filling of the kilns can be put up to the workman.

DISCUSSION

Mr. Watts: What percent of the total kiln capacity can you get in terra-cotta?

Mr. Doe: A good setting of terra-cotta depends upon the character of the work but it is usually forty percent of the space, running from thirty-three to forty-five and in some cases to fifty percent.

Mr. Gates: I have found it to be between thirty and forty percent according to the kind of work the shop was running.

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THE HYDRATION OF PORTLAND CEMENT*

BY A. A. KLEIN AND A. J. PHILLIPS

The Geophysical Laboratory[1] studying the ternary system CaO, SiO_2, Al_2O_3 has established the constitution of all the definite combinations, CaO and Al_2O_3; CaO and SiO_2; SiO_2 and Al_2O_3, and CaO, SiO_2 and Al_2O_3. Furthermore, this laboratory[2] has verified the work of the Geophysical Laboratory and determined which of these compounds are actually present in Portland cement clinker. With the constitution of cement thus definitely established, it was thought advisable to take up the study of the effects of various amounts of water and steam at atmospheric and high pressures on the individual cement compounds and on Portland cement itself.

The work consisted of the preparation of the constituent binary compounds in as pure and homogeneous condition as possible. These synthetic compounds were three aluminates—$CaO . Al_2O_3$; $5\,CaO . 3\,Al_2O_3$, and $3\,CaO . Al_2O_3$—4 Silicates—$CaO . SiO_2$; $\gamma\ 2\,CaO . SiO_2$; $\beta\ 2\,CaO . SiO_2$ and $3\,CaO . SiO_2$—and lime burned at different temperatures. For the preparation of these, recourse was had to an up-draft kiln. Where higher temperatures were needed, a carbon resistance electric furnace was employed. The raw products were C. P. calcium carbonate, alumina and silica. These were mixed in the proper proportions, burned for one day, ground, examined microscopically, remoulded and reburned, this process being repeated until a satisfactory sample was obtained. In addition to the above compounds tests were made on a high silica cement, a low silica cement, and a high iron cement.

The above compounds were hydrated on microscope slides with an excess of water, under conditions which precluded evaporation and the action of CO_2. They were also hydrated in a cylinder with superheated steam at atmospheric pressure, according to the method proposed by Bied,[3] and in an autoclave

* By permission of the Director of the Bureau of Standards.
[1] *J. Ind. Eng. Chem.*, 3, 211-27.
[2] *Concrete-Cement Age*, 2, (Cement Mill Section), 3-7.
[3] *Proc. Int. Assoc. Testing Mat.*, 2, (9) 8.

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with steam at various temperatures and pressures. Finally, they were moulded with limited quantities of water approximating those used in normal consistency mixes. In addition to water, lime-water and calcium sulfate solution were employed as hydrating mediums. All hydration products were examined by petrographic methods to determine the changes taking place.

The hydration products are briefly tabulated in Tables I, II, III and IV.

Fig. 1—$3\,CaO.Al_2O_3$ in water with crossed nicols. Needles are $3\,CaO.Al_2O_3.xH_2O$. Hexagonal plates not visible between crossed nicols. Magn.=250 diam.

It was found that with an excess of water $3\,CaO\,.\,Al_2O_3$ hydrates as $3\,CaO.Al_2O_3.xH_2O$ where x varies with the drying conditions. This compound crystallizes in hexagonal plates, needles, which are the plates turned on edge, and radial spherulites which consist of needle aggregates radiating from a common center. See Fig. 1. With polarized light and crossed nicols, they exhibited a medium double refraction and are uniaxial, positive. The refractive indices for Na light are as follows: $e=1.552\pm0.003$ and $o=1.535\pm0.003$. The character of the

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principal zone is positive. The plates are orientated perpendicular to the c crystallographic axis, and the needles are parallel to it.

$5\,CaO.3\,Al_2O_3$ and $CaO.Al_2O_3$ on hydrating split off amorphous hydrated alumina and form $3\,CaO.Al_2O_3.xH_2O$. See Figs. 2a, 2b, 3a and 3b. Under actual cement conditions such as typified by the moulded specimens, the above crystallized compound does not form immediately but separates from solution as an amorphous material. In the steamer at atmospheric pressure, a little crystallized aluminate is formed with the amorphous material, still more in the autoclave, and finally on microscopic slides $3\,CaO.Al_2O_3.xH_2O$ is entirely crystallized. Wherever the amorphous aluminate is formed it slowly but eventually changes to the crystallized compound.

The hydration of the aluminates begins readily in all cases. With an excess of water the reaction proceeds quickly, and in a few days the aluminates are completely hydrated. With restricted amounts of water, however, the individual aluminate grains become coated with amorphous hydrated aluminate, through which further action proceeds with more or less difficulty.

In steam at atmospheric pressure, the tests showed that the weakly basic aluminates do not absorb water above 110°, while the more basic aluminates absorb water up to 140°. Furthermore, a specimen of $3\,CaO.Al_2O_3$ containing high burned lime absorbs water at 175°.

The nature of the lime hydrate formed by the hydration of free lime with plenty of water, and the readiness with which it hydrates depends upon the fineness of the lime grains and the burning temperature. With coarser lime grains and with highly burned lime, the hydration proceeds less quickly and produces a preponderance of crystallized lime hydrate. On the other hand, with fine lime grains and with low burned lime mainly amorphous hydrate is formed, and the reaction proceeds more quickly. Lime hydrate crystals are much more inactive chemically than the amorphous variety. White's solution,[4] which is a solution of

[4] *J. Ind. Eng. Chem.*, 1, 5.

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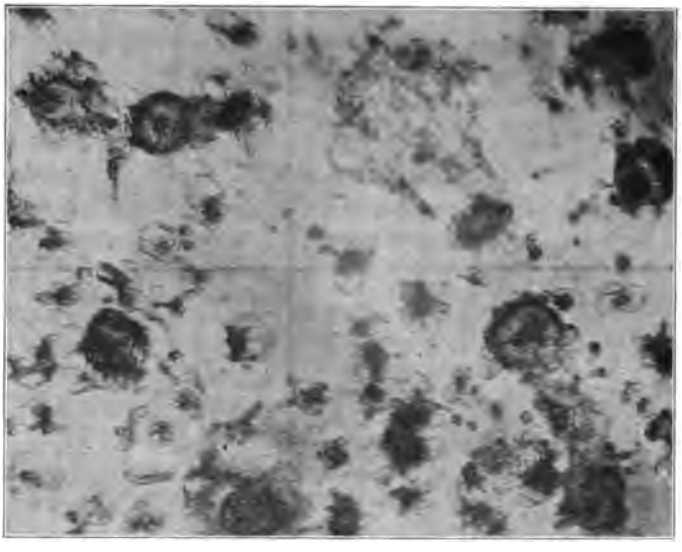

Fig. 2a—5 $CaO.3\ Al_2O_3$, in water without nicols. Spherulites, needles, and hexagonal plates of $3\ CaO.Al_2O_3.xH_2O$ and a little amorphous material. Magn.=180 diam.

Fig. 2b—5 $CaO.3\ Al_2O_3$, in water without nicols. Plates and needles of $3\ CaO.Al_2O_3.xH_2O$ and amorphous alumina. Magn.=300 diam.

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phenol in nitrobenzol to which a couple drops of water is added, attacks the amorphous hydrate almost instantly but reacts extremely slowly with the crystals. See Fig. 4. In the autoclave the amorphous variety is not changed, whereas free lime yields, according to its fineness and burning temperature, crystallized or amorphous hydrate. The crystals, in this case, often grow to large size, depending upon the length of time of reaction, the temperature and the pressure.

Lime hydrate crystallizes as short, flaky, tabular, hexagonal crystals, also as more or less elongated hexagonal prisms. Twinning has never been observed, but the crystals sometimes show parallel grouping and skeletal development. Very good cleavage is observed parallel to (0001). Under the microscope, lime hydrate crystals possess a clear, hexagonal outline when orientated perpendicular to the c. crystallographic axis, but when resting on edge they exhibit a prismatic to an acicular structure. The double refraction is medium, the interference colors varying considerably with the thickness of the grain and its orientation. Some of the hydrate crystals are thick enough to show third and fourth order interference colors. The indices of refraction for Na light are as follows: $o=1.582\pm0.002$, $e=1.559\pm0.002$, e-o (measured)$=0.023\pm0.003$. The interference figure is uniaxial and the optical character negative. Lime hydrate resembles $3\,CaO\,.\,Al_2O_3\,.\,xH_2O$ very closely, but is differentiated by the fact that the crystals of the former are invariably larger, have higher indices of refraction and a different optical character.

Hydration of the aluminates in lime water reveals the same compounds as in distilled water. No new type of crystals, which might indicate hydrated $4\,CaO\,.\,Al_2O_3$, was observed. There does seem to be an action, however, between the hydrated alumina split off and the lime hydrate of the solution, resulting in a greater development of crystallized $3\,CaO\,.\,Al_2O_3\,.\,xH_2O$.

Aluminates hydrated in the autoclave with an excess of lime water give no new type of compound. The plate crystals of $3\,CaO\,.\,Al_2O_3\,.\,xH_2O$ are rather poorly developed. The addition of dry lime hydrate up to 50 percent decidedly retards the crystal growth of the aluminates in the autoclave.

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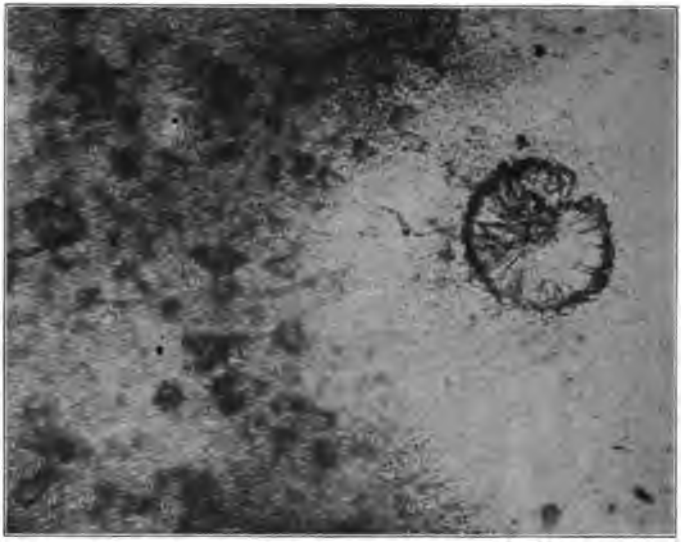

Fig. 3a—$CaO.Al_2O_3$ in water showing large spherulite, amorphous material and crystal covered by amorphous material. Magn.=165 diam.

Fig. 3b—The same as Fig. 3a except in crossed nicols. Brings out crystal covered with amorphous material.

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The first effect of gypsum solution on the aluminates is to retard the formation of amorphous hydrated material, and to keep the pores of the material open to the further penetration of water. Specimens hydrated in saturated gypsum solutions show the highest ignition loss after six days. The products of hydration are the same as those with distilled water, with the exception of the additional formation of sulfo-aluminate needles. This new compound is identical for all three aluminates, and its formula is $3\,CaO:Al_2O_3.3\,CaSO_4.xH_2O$. See Figs. 5 and 6. It crystallizes in crystals showing long prismatic development. Irregular intergrowths are occasionally observed, but twinning is not noted. The crystals show very low interference colors ranging from black to white of the first order. The character of the principal zone is negative and the extinction parallel. The indices are lower than 1.48. Interference figures are biaxial with a large optic axial angle. The optical character is positive. The crystals of $3\,CaO.Al_2O_3.3\,CaSO_4.xH_2O$ can be readily distinguished from $3\,CaO.Al_2O_3.xH_2O$ by their different development, lower refraction, lower double refraction and different character of the principal zone. The formation of $3\,CaO.Al_2O_3$ $3\,CaSO_4.xH_2O$ is only incidental in the retardation of the initial set, since it is formed before, during and after this set. Variation of the gypsum content above and below a certain definite concentration causes a decrease in the setting time.

The problem of initial set is one involving the action of small amounts of electrolytes in retarding the coagulation of the amorphous aluminate material. The evidence is in favor of the fact that the aluminates coagulate and separate as amorphous bodies from supersaturated solutions, the rate of coagulation being affected by such small quantities of electrolyte as to preclude the possibility of the reaction being solely a chemical one. Thus with a certain and definite concentration of gypsum, maximum hydration is attained, and at the same time the rate of coagulation is retarded increasing the time of set.

Sulfo-aluminate crystals are broken up in the autoclave as is a'so gypsum. Club-shaped crystals are noted with optical properties that suggest a composition between $CaSO_4.2\,H_2O$

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and $CaSO_4$. With higher temperatures and pressures, water is even driven out of the amorphous hydrated aluminate. Gypsum favors the growth of $3\,CaO\,.\,Al_2O_3\,.\,xH_2O$ crystals in the autoclave.

$CaO.SiO_2$, as well as γ $2\,CaO.SiO_2$ are practically inert with regard to hydration. β $2\,CaO\,.\,SiO_2$ is but slightly hydrated in water after a considerable length of time. This is

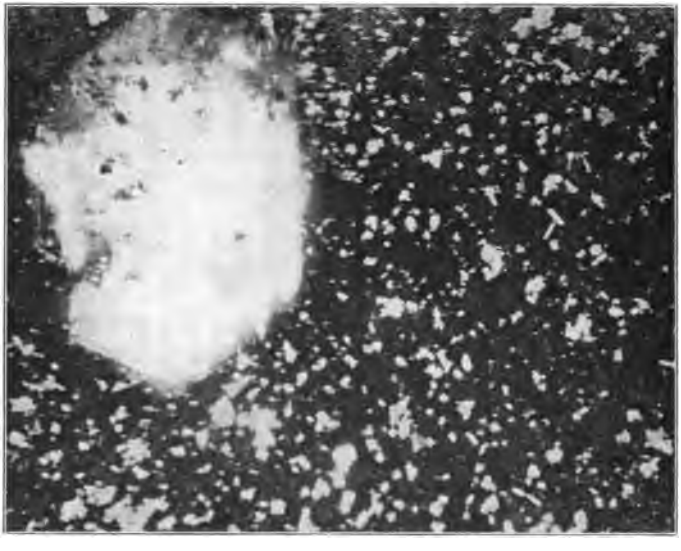

Fig. 4—White's phenolate test on crystallized and amorphous $Ca(OH)_2$. The large hexagonal crystal is $Ca(OH)_2$ unacted upon; the smaller prismatic crystals are Ca phenolate formed by the action of White's solution on amorphous $Ca(OH)_2$. Magn.=280 diam.

manifested by a slight etching of the grains and the formation of a small amount of gel-like material. The presence of lime water and plaster solution does not materially increase the hydration. Treatment with $3\,CaO.Al_2O_3$ solution gave maximum hydration and best 28 day test pieces. In mixtures of β $2\,CaO.SiO_2$ and the aluminates, the latter show some hydration while the former is unhydrated after 24 hours the time when cements are exposed to accelerated tests. At 28 days, the aluminates are completely hydrated, and β $2\,CaO\,.\,SiO_2$ shows quite a little hy-

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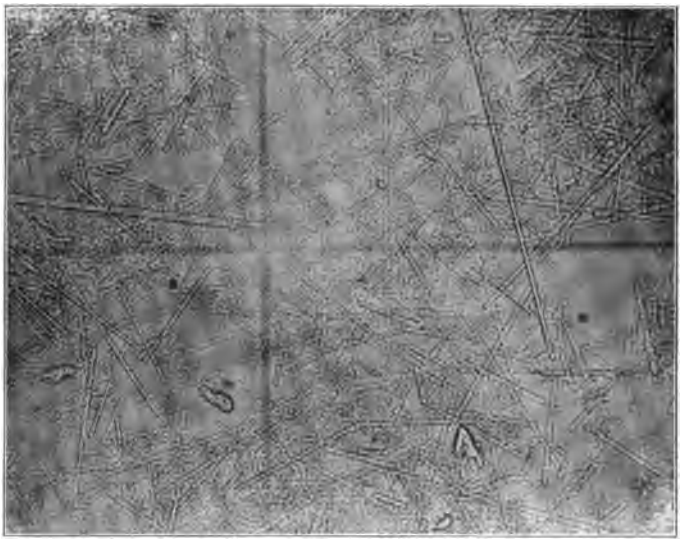

Fig. 5—3 $CaO.Al_2O_3.3\ CaSO_4.xH_2O$ crystals formed by the addition of gypsum solution to a 3 $CaO.Al_2O_3$ solution. Magn.=400 diam.

Fig. 6—3 $CaO.Al_2O_3.3\ CaSO_4.xH_2O$ formed by hydrating 3 $CaO.Al_2O_3$ in a gypsum solution. Magn.=280 diam.

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dration. The test pieces, while exhibiting fairly good rigidity, have not the strength of corresponding cement briquettes.

The slides of β 2 CaO . SiO_2 and aluminates indicate that the hydration of the aluminates proceeds as previously noted, and that with an excess of water, the β 2 CaO . SiO_2 hydrates more quickly, the product being the same amorphous gel-like material. Neither crystallized nor amorphous lime hydrate is split off when β 2 CaO . SiO_2 hydrates, nor are there any needles of hydrated CaO . SiO_2 formed. See Fig. 7. The hydration product is 2 CaO . SiO_2+Aq. which so far has been observed only as an amorphous body.

Homogeneous 3 CaO . SiO_2 was not obtained, the product used containing an extremely small amount of lime, β 2 CaO SiO_2 and 3 CaO . Al_2O_3. The compound 3 CaO . SiO_2 acts entirely differently with respect to hydration from either the β 2 CaO . SiO_2 or mixtures of β 2 CaO . SiO_2 and lime. It hydrates readily with excess of water, with limited water, and in the autoclave. The products of hydration are identical, consisting of lime hydrate crystals, and amorphous hydrated silicate. The compound 3 CaO . SiO_2 sets hard in five hours and shows no sign of disintegration after 28 days in water. The size of the lime hydrate crystals depend upon the pressure in the autoclave, in general the greater the pressure the larger the crystals. Mixing 3 CaO . SiO_2 with β 2 CaO . SiO_2 has no favorable effect on the hydration of the latter.

Mixtures of 3 CaO . SiO_2 and the aluminates gauged with water, lime water and calcium sulphate solution show first the beginning of hydration of the aluminate, followed shortly by the hydration of 3 CaO . SiO_2. See Figs. 8 and 9. Twenty-eight day specimens are extremely dense, hard and strong, comparing very favorably with neat cement briquettes. Again, there is an absence of hydrated CaO . SiO_2 needles. The evidence favors the fact that 3 CaO . SiO_2 on hydrating splits off one molecule of lime hydrate and forms the amorphous hydrated 2 CaO . SiO_2, this compound being identical with that formed by β 2 CaO, SiO_2.

The hydration of cements is thus brought about by the for-

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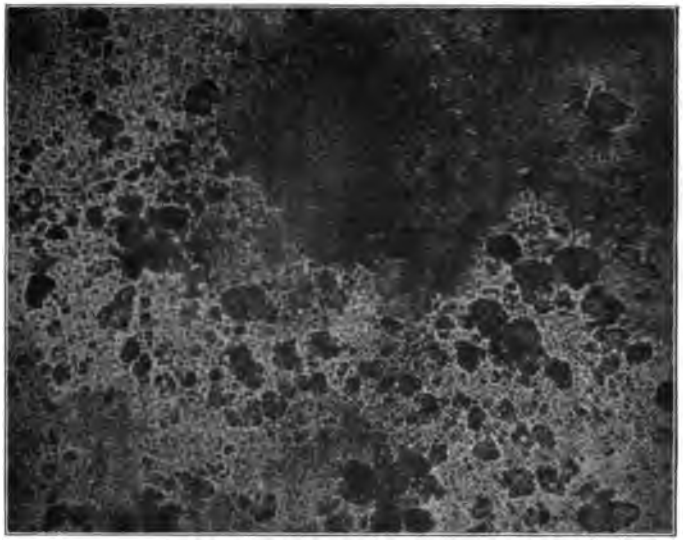

Fig. 7—Amorphous hydrated $2\,CaO.SiO_2$ taken from a slide of β $2\,CaO.SiO_2$ and $3\,CaO.Al_2O_3$. Note absence of $Ca(OH)_2$ crystals. Magn.=200 diam.

Fig. 8—$3\,CaO.SiO_2$ and $3\,CaO.Al_2O_3$ showing large $Ca(OH)_2$ crystal and smaller hydrated $3\,CaO.Al_2O_3$ needles covered with amorphous hydrated silicate. Magn.=160 diam.

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mation of amorphous hydrated $3\,CaO\,.\,Al_2O_3$ with or without amorphous alumina, the aluminate later crystallizing. At the same time sulfo-aluminate crystals are formed; and low burned or finely ground lime hydrates. The formation of the above compounds begins within a few hours after the cement is gauged. The next compound to react is $3\,CaO\,.\,SiO_2$. Its hydration may begin within 24 hours, and it is generally completely hydrated within seven days. Between seven and twenty-eight days the amorphous aluminate commences to crystallize, and β $2\,CaO\,.\,SiO_2$ begins to hydrate. See Fig. 10. Although the latter is the chief constituent of American Portland cements it is the least reactive compound. The early strength (24 hours) of cements are due to the hydration of any lime present and of the aluminates. The increase in strength between 24 hours and 7 days depends upon the hydration of $3\,CaO\,.\,SiO_2$, although the further hydration of the aluminates may contribute somewhat. The increase between 7 and 28 days is due to the hydration of β $2\,CaO\,.\,SiO_2$, but here is encountered opposing forces with the hydration of the very high burned free lime, and the crystallization of the aluminates. It is to this hydration that the falling off in strength between 7 and 28 days of very high limed cements is due, whereas the decrease shown by the high alumina cements is due to the crystallization of the aluminate. Finally the Fe in a cement is resistive to hydration and does not form any definite crystalline hydration products but occurs as a rust-like material.

Several experimenters have concluded that the reactions taking place in the autoclave are abnormal and bear no relation to those taking place in normal hydration. In all the considerable work done with the autoclave, no evidence of abnormal hydration has been found, except in the changing of the optical properties of the gypsum and hydrated $3\,CaO\,.\,Al_2O_3$. This dehydration has been overcome by using more water in the autoclave, and the resulting crystals have been very slightly altered. Using very high pressures (600 lbs. at 2 hours), there have been observed large growths of lime hydrate crystals which could be removed with forceps; but with lower pressures such as ordi-

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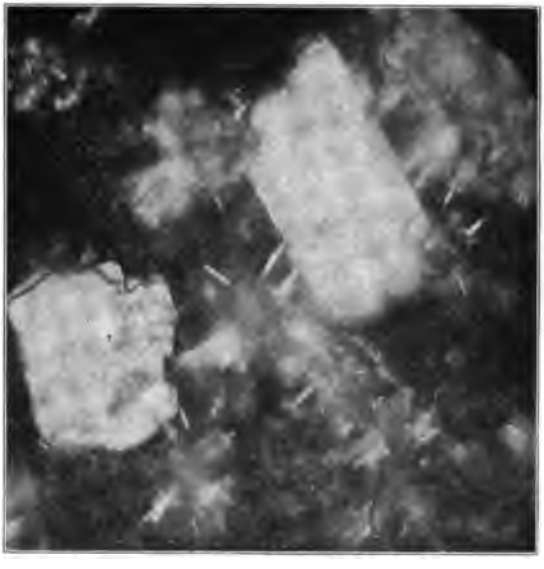

Fig. 9—3 $CaO.SiO_2$ and 5 $CaO.3\ Al_2O_3$ in water with crossed nicols showing large $Ca(OH)_2$ crystals, needles and spherulites of 3 $CaO.Al_2O_3.xH_2O$.

Fig. 10—White cement in water with crossed nicols. $Ca(OH)_2$ crystals partly covered with amorphous material, also 3 $CaO.Al_2O_3.xH_2O$ needles. Magn.=280 diam.

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narily used, they would more nearly approximate those found at 28 day normal hardening.

The disintegrating action attributed to the crystallization of $3\,CaO\,.\,Al_2O_3\,.\,3\,CaSO_4\,.\,xH_2O$ has been greatly exaggerated. Though this compound does crystallize with large amounts of water, the crystals produced in a hydrated cement are extremely small. Under the microscope the maximum length attained is never over 0.04 m.m. In sea water or in alkaline water, the presence of other salts in solution may assist in the development of larger crystals, which might then exert an expansive force. Another fact, which argues against their having any considerable disruptive action, is that they begin to form about the time of the beginning of hydration of the aluminate, and before the cement mass has begun to assume any great rigidity.

It is to the growth of large lime hydrate crystals that failures in accelerated tests must be attributed. These are not due to the increase in volume owing to formation of lime hydrate, but result from pressure caused by growing crystals.

The ability of lime to form either crystalline or amorphous lime hydrate on hydration, depending upon fineness and burning temperature, explains the behavior of various cements in the accelerated tests. For instance (1) some cements will not pass the boiling test, (2) some will pass the boiling test but not the autoclve, (3) and others will pass either test after aging, where previously they would not. In the first case the lime is sufficiently fine and high burned so that in the boiling test it hydrates, crystallizes, and the growth of crystals is sufficient to cause disintegration. In the second case the lime may be so coarse or highly burned as not to hydrate in the boiling test but only in the autoclave, due to the high temperature and pressure employed. In the third case aeration with insufficient water to allow solution and crystallization has caused the lime to hydrate to the amorphous condition, and in the accelerated tests there is no formation of crystals from the amorphous material, hence no disintegration.

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TABLE I—ALUMINATES

		SLIDES	STEAMING	AUTOCLAVE	MOULDED SPECIMENS
$3\,CaO\,.\,Al_2O_3$	With H_2O	Needles and hex. plates of $3\,CaO.Al_2O_3.xH_2O$. No amorphous material.	Absorbs water to 140°. Needles, crystals and a few plates. A little amorphous material, also unhydrated $3\,CaO\,.\,Al_2O_3$.	Considerable amorphous material, a few needles and plates. No unhydrated material.	Hydration product after 24 hrs. entirely amorphous, grains show unhydrated centers and hydrated edges.
	With $Ca(OH)_2$	Same constituents as with water. No new type crystals denoting hydrated $4\,CaO.Al_2O_3$ observed.	No tests made.	With $Ca(OH)_2$ solution products same as above with greater number of plate crystals. With dry $Ca(OH)_2$ crystallization is retarded and amount of amorphous hydrated aluminate increased.	7 day specimens still contain a few unhydrated grains. Hydrated material is mainly amorphous with a few small plates and needles. 28 day specimens are completely hydrated and show increase in needles and plates.

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TABLE I—Continued

		SLIDES	STEAMING	AUTOCLAVE	MOULDED SPECIMENS
$3\,CaO\,.\,Al_2O_3$	With $CaSO_4$	Crystals of $3\,CaO.Al_2O_3.xH_2O$ formed together with extremely fine needles of $3\,CaO\,.\,Al_2O_3\,.\,3\,CaSO_4\,.\,xH_2O$.	No tests made.	Sulfo aluminate crystals destroyed. Club crystals noted with optical properties denoting a comp. between $CaSO_4$ $2\,H_2O$ and $CaSO_4$. Also large needles and plates of $3\,CaO$, $Al_2O_3\,.\,x\,H_2O$ and amorphous material.	7 day specimens show very little unhydrated aluminate. Hydration products are both crystalline and amorphous $3\text{-}CaO\,.\,Al_2O_3\,.\,x\text{-}H_2O$ and sulfo aluminate crystals.
$5\,CaO\,.\,3\,Al_2O_3$	With H_2O	Needles, plates and radial spherulites of $3\,CaO\,.\,Al_2O_3.\,xH_2O$ and some amorphous material (hydrated Al_2O_3).	Absorbs water to 140°. Splits off hydrated Al_2O_3 and forms $3CaO\,Al_2O_3\,.\,xH_2O$. Considerable unhydrated aluminate.	Amorphous material, plates and lath shaped crystals of $3\,CaO\,.\,Al_2O_3\,.\,x\text{-}H_2O$. No unhydrated material.	After 24 hours chiefly amorphous material, very little crystal development. Unhydrated centers.

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$5\,CaO\,.3\,Al_2O_3$	With $Ca(OH)_2$	Same constituents as with water.	No tests made.	With $Ca(OH)_2$ solution product same as above. With solid $Ca(OH)_2$ crystallization is retarded and amorphous material increased.	7 day specimens contain a little unhydrated aluminate, also amorphous material and a few $3\,CaO\,.\,Al_2O_3\,xH_2O$ crystals. 28 day specimens are completely hydrated and show considerable increase in needles and plates.
	With $CaSO_4$	Hydration products are crystals of $3\,CaO\,Al_2O_3\,.\,x\,H_2O$, amorphous hydrated Al_2O_3 and sulfo aluminate crystals.	No tests made.	Sulfo aluminate crystals destroyed. Quite a quantity of $3\,CaO\,.\,Al_2O_3\,.\,xH_2O$ crystals noted. Amorphous material and club shaped crystals of $CaSO_4\,.\,xH_2O$ observed.	7 day specimens show a little unhydrated material. Hydration products are crystallized $3\,CaO\,.\,Al_2O_3\,.\,xH_2O$ and amorphous hydrated material, also sulfo aluminate.

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TABLE I—Continued

		SLIDES	STEAMING	AUTOCLAVE	MOULDED SPECIMENS
$CaO \cdot Al_2O_3$	With H_2O	Crystalized material consists of needles, plates and spherulites of $3\,CaO \cdot Al_2O_3\,xH_2O$. Also considerable amorphous hydrated Al_2O_3.	Absorbs water to 110° with formation of amorphous hydrated Al_2O_3, crystalline $3\,CaO.Al_2O_3\,xH_2O$. Considerable unhydrated material noted.	Considerable amorphous material, also needles and plates of $3\,CaO, Al_2O_3 \cdot x\,H_2O$.	Hydration product after 24 hrs. Almost entirely amorphous, with few needle crystals.
	With $Ca(OH)_2$	Same constituents as with water.	No tests made.	With $Ca(OH)_2$ solution same products as with H_2O. Solid $Ca(OH)_2$ up to 50 percent favors the formation of amorphous hydrated material.	7 day specimens contain a little unhydrated material, much amorphous material and quite considerable crystallized $3\text{-}CaO \cdot Al_2O_3 \cdot x\text{-}H_2O$, greater amount than in corresponding H_2O specimen. 28 day specimens contain no unhydrated material.

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$CaO . Al_2O_3$	With $CaSO_4$	Crystals of $3 CaO . Al_2O_3 . xH_2O$, considerable amorphous hydrated Al_2O_3, well developed crystals of $3 CaO . Al_2O_3 . 3 CaSO_4 . xH_2O$.	No tests made.	Contains a few $3 CaO . Al_2O_3 . xH_2O$ crystals, considerable amorphous material and club shaped crystals.	7 day specimens are all hydrated and consist of amorphous material, needles and plates of $3 CaO . Al_2O_3 . xH_2O$, also sulfo aluminate crystals.

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TABLE II—SILICATES

		SLIDES	STEAMING	AUTOCLAVE	MOULDED SPECIMENS
$CaO \cdot SiO_2$	With H_2O	No hydration	No hydration	Extremely slight etching.	No hydration
	With $Ca(OH)_2$	No hydration	No tests	No tests	No tests
	With $CaSO_4$	No hydration	No tests	No tests	No tests
$\gamma\ 2CaO \cdot SiO_2$	With H_2O	No hydration	Extremely slight hydration (0.52 percent H_2O absorbed).	Trace of hydration.	No hydration
	With $Ca(OH)_2$	No hydration	No tests	No tests	No tests
	With $CaSO_4$	No hydration	No tests	No tests	No tests
$\beta\ 2CaO \cdot SiO_2$	With H_2O	No hydration until after considerable length of time.	No hydration	Slight etching and formation of minute quantities of gel-like material.	No hydration
	With $Ca(OH)_2$	Practically no different from specimens in H_2O.	No hydration	Slight etching and formation of gel-like material in minute quantities.	28 day specimens consist almost entirely of unhydrated $\beta\ 2CaO, SiO_2$ with a little amorphous material.

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β 2 CaO . SiO_2	With $CaSO_4$	Practically no different from specimens in H_2O.	No hydration	Slight etching and formation of minute quantities of gel-like material.	28 day specimens consist almost entirely of unhydrated 2 CaO, SiO_2 with a little amorphous material.
	With 3 CaO Al_2O_3 soln.	No tests	No tests	No tests	28 day specimens show much greater hydration of orthosilicate with formation of amorphous hydrated material but no $Ca(OH)_2$. 2CaO SiO_2 shaken with large excess of soln. for 10 days shows maximum hydration and ignition loss of 4.04 percent.

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TABLE II—Continued

		SLIDES	STEAMING	AUTOCLAVE	MOULDED SPECIMENS
$3\,CaO\,.\,SiO_2$	With H_2O	Started to hydrate within 24 hours with formation of crystals of $Ca(OH)_2$ and amorphous hydrate silicate. After 3 weeks hydration the slide was covered with amorphous material.	A slight amount of H_2O absorbed both at 140° and up to 200°, due to hydration of CaO present.	Hydration products are amorphous hydrated $2\,CaO\,.\,SiO_2$ and crystals of $Ca(OH)_2$ whose size increase with increase in pressure. Specimen completely hydrated.	Spec. with 20 percent H_2O set hard at the end of 5 hours showed no disintegration after 28 days. Hydration products are amorphous $2CaO\,SiO_2\,.\,xH_2O$ and crystalline $Ca(OH)_2$.
	With $Ca(OH)_2$	Started to hydrate within 24 hours with formation of crystallized $Ca(OH)_2$ and amorphous hydrated silicate. After 3 weeks hydration the slide was covered with amorphous material.	No tests made	No tests made	No tests made

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$3\,CaO\,.\,SiO_2$	With $CaSO_4$	Started to hydrate within 24 hours with formation of crystals of $Ca(OH)_2$ and amorphous hydrated silicate. After 3 weeks hydration slide was covered with amorphous material.	No tests made	Products are the same as with $3\,CaO\,.\,SiO_2$ hydrated in the autoclave with H_2O.	Spec. with 20 percent $CaSO_4$ solution set up hard and showed no disintegration at end of 28 days. Hydration products same as with hydration in H_2O.
$3\,CaO\,.\,SiO_2$ and $\beta\,2\,CaO\,.\,SiO_2$ with plaster				Trisilicate completely hydrated. Orthosilicate very slightly hydrated.	

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TABLE III—SILICATES AND ALUMINATES

		SLIDES	STEAMING	AUTOCLAVE	MOULDED SPECIMENS
$CaO \cdot SiO_2$ and aluminates	With H_2O	Aluminates hydrate to usual products. Silicate entirely unhydrated.	No tests made	No tests made	No tests made
	With $Ca(OH)_2$	Same as with H_2O	No tests made	No tests made	No tests made
	With $CaSO_4$	Same as with H_2O	No tests made	No tests made	No tests made
γ $2CaO \cdot SiO_2$ and aluminates	With H_2O	Aluminates hydrate as usual, but silicate is entirely resistant.	No tests made	No tests made	No tests made
	With $Ca(OH)_2$	Same as with H_2O	No tests made	No tests made	No tests made
	With $CaSO_4$	Same as with H_2O	No tests made	No tests made	No tests made

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β 2 CaO . SiO_2 and aluminates	With H_2O	Aluminates began to hydrate first to usual hydration products. Silicate began to be etched in less than a week and amorphous hydrated silicate was formed. At end of 3 weeks silicate covered the whole slide. No $Ca(OH)_2$ was noted.	Aluminates hydrated to quite an extent. β 2 CaO . SiO_2 unhydrated.	Aluminates hydrated. Orthosilicate but slightly etched.	28 day specimens somewhat friable. Aluminates hydrated entirely to usual hydration products. Silicate hydrated to quite an extent. No $Ca(OH)_2$ observed.
	With $Ca(OH)_2$	Same as with H_2O	No tests	No tests	Same as with H_2O with a slight increase in amount of hydrated material.
	With $CaSO_4$	Same as with H_2O with the additional formation of 3 CaO . Al_2O_3 3 $CaSO_4$. xH_2O crystals.	No tests	Same as with H_2O but for the additional formation of $CaSO_4$. xH_2O crystals.	Same as with H_2O with the formation of sulfoaluminate needles.

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TABLE III—Continued

		SLIDES	STEAMING	AUTOCLAVE	MOULDED SPECIMENS
$3\,CaO\,.\,SiO_2$ and aluminates	With H_2O	Aluminates began to hydrate first. Trisilicate started to hydrate within 24 hrs. to $Ca(OH)_2$ and amorphous hydrated $2\,CaO,\,SiO_2$. The latter covered slide in a week.	Aluminates hydrated to quite an extent. Trisilicate is slightly hydrated.	Both silicate and aluminate hydrated. $Ca(OH)_2$ crystals grow to large size.	28 day specimens hard and compact. Show complete hydration of silicate and aluminate. Amorphous aluminate has begun to crystallize. Amorphous hydrated silicate noted, also $Ca(OH)_2$ crystals.
	With $Ca(OH)_2$	Same as with H_2O	No tests	No tests	Same as with H_2O
	With $CaSO_4$	Same as with H_2O with the additional formation of sulfo-aluminate crystals.	No tests	Same as with H_2O with the additional formation of $CaSO_4\,.\,xH_2O$ crystals.	Same as with H_2O with the additional formation of sulfo aluminate crystals.

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TABLE IV—CEMENTS

		No. 1	No. 2	No. 3	No. 4
ANALYSES	SiO_2	25.02	23.68	24.59	20.37
	Al_2O_3	6.08	5.10	6.49	3.64
	Fe_2O_3	0.49	0.37	2.64	8.97
	CaO	62.89	62.69	61.04	61.41
	MgO	1.11	1.96	1.71	0.82
	SO_3	1.75	1.37	1.45	1.19
	Na_2O	0.11	0.03	0.12	1.54
	K_2O	0.56	0.30	0.40	0.24
	CO_2	1.08	0.51	0.93	1.04
	H_2O	0.95	4.08	0.75	1.06
24 hrs.		No $Ca(OH)_2$ crystals, a little isotropic amorphous $Ca(OH)_2$. 3 CaO . SiO_2 very slightly hydrated. Orthosilicate unhydrated. Aluminate considerably hydrated to amorphous material. No needles or plates present.	Some amorphous $Ca(OH)_2$. No crystals. Amorphous hydrated trialuminate, trisilicate slightly hydrated. Orthosilicate unchanged.	Very little amorphous $Ca(OH)_2$. Aluminate hydrated to amorphous material. Trisilicate and orthosilicate unhydrated.	A few very small $Ca(OH)_2$ crystals with some amorphous $Ca(OH)_2$. Trisilicate hydrated a little. Orthosilicate unhydrated. Trialuminate nearly all hydrated to amorphous material.

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TABLE IV—Continued

	No. 1	No. 2	No. 3	No. 4
7 days	A large number of $Ca(OH)_2$ crystals and some amorphous hydrate. Trisilicate all hydrated. Orthosilicate slightly hydrated. Aluminate all hydrated to amorphous material with a few needles and plates.	$Ca(OH)_2$ crystals not as well developed as in No. 1 (7 days); amorphous hydrate. Trisilicate almost all hydrated. Aluminate hydrated to a few needles and plates and much amorphous material.	$Ca(OH)_2$ crystallized and small amounts of amorphous $Ca(OH)_2$ noted. Trisilicate all hydrated. Orthosilicate very slightly hydrated. Aluminate hydrated to amorphous material with a few needles and plates.	$Ca(OH)_2$ crystals large and more plentiful than in No. 4 (24 hrs.) sample. Amorphous hydrate. Trisilicate all hydrated. Orthosilicate slightly hydrated. Hydrated aluminate consists of amorphous material with some needles and plates.
28 days	Large amount of $Ca(OH)_2$ crystals and some amorphous hydrate. Trisilicate all hydrated. Orthosilicate considerably hydrated, the hydrated silicate product in both cases being amorphous. Aluminate nearly all in fine needles and plates, a smaller amount being still amorphous.	Large crystals of $Ca(OH)_2$. Some amorphous $Ca(OH)_2$. Trisilicate all hydrated. Orthosilicate not very greatly hydrated. Hydrated aluminate needles and small plates rather plentiful.	Plenty of $Ca(OH)_2$ crystals and a little amorphous $Ca(OH)_2$. Trisilicate all hydrated. Orthosilicate partly hydrated, surrounded by amorphous material. Trialuminate present as needles, plates and amorphous material.	A large number of $Ca(OH)_2$ crystals and some amorphous material. Trisilicate all hydrated. Quite a little orthosilicate still unhydrated. Aluminate as needles, plates and amorphous material. Fe material slightly hydrated to opaque reddish substance resembling Fe rust.

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Autoclave after 24 hrs. in damp closet.	Very large $Ca(OH)_2$ crystals and some amorphous hydrate. Trisilicate all hydrated. Orthosilicate considerably hydrated. Aluminate all hydrated to amorphous material and needles.	Large $Ca(OH)_2$ crystals, some amorphous hydrate. Trisilicate hydrated. Orthosilicate, but slightly hydrated. Trialuminate all hydrated to amorphous material and needles.	$Ca(OH)_2$ crystals larger than any of the others. Some amorphous hydrate. Trisilicate hydrated. Orthosilicate partially hydrated. Trialuminate hydrated to amorphous material and needles.	Large $Ca(OH)_2$ crystals, some amorphous hydrate. Trisilicate all hydrated. Much orthosilicate still unhydrated. Hydrated trialuminate needles and amorphous material observed. Fe material hydrated to reddish opaque fine grained material.

NOTE: Sulpho-aluminate crystals observed in all specimens except those in the auto-clave, where they are destroyed and $CaSO_4.xH_2O$ formed.

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A TYPE OF CRYSTALLINE GLAZE AT CONE 3

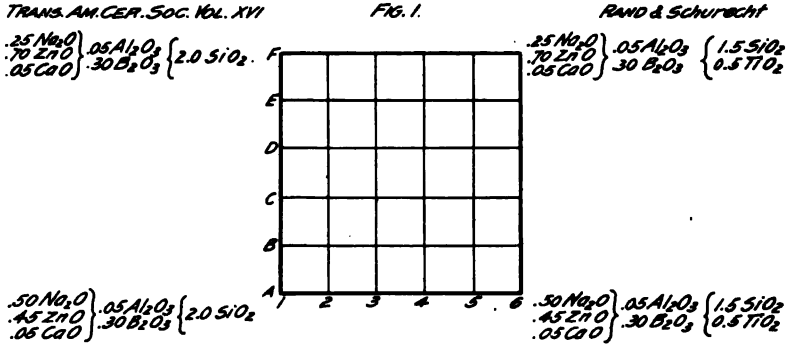
C. C. RAND AND H. G. SCHURECHT, URBANA, ILL.

The glazes under consideration are of a type designed to mature about cone 3 to 4. The Al_2O_3 is maintained constant throughout at .05 equivalent and is introduced as Pikes No. 20 English ball clay. In general the group resembles Worcester's[1] best raw clay glaze. His formula was

$$\left.\begin{array}{l} 0.33\tfrac{1}{3}\ Na_2O \\ 0.66\tfrac{2}{3}\ ZnO \end{array}\right\}\ 0.03\ Al_2O_3\ \left\{\begin{array}{l} 1.60\ SiO_2 \\ 0.20\ B_2O_3 \end{array}\right.$$

He concludes, however, that .05 Al_2O_3 generally seems the most favorable and that many German formulæ call for this amount.

A group of 36 glazes was made with a view to determine the effect of varying ZnO against Na_2O along the ordinate and rutile against flint along the abscissa.



The arrangement of the group with the formulæ of the four corners are shown in Fig. 1, the vertical series being designated by numbers, the horizontal series by letters.

Two frits of the following compositions were used:

No. 1

$$\left.\begin{array}{l} 0.25\ Na_2O \\ 0.70\ ZnO \\ 0.05\ CoO \end{array}\right\} 0.30\ B_2O_3\ \}\ \ 1.4\ SiO_2$$

[1] Vol. X *Trans. Amer. Cer. Soc.*, p. 150. Function of Alumina in Crystalline Glaze.

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No. 2

$$\left.\begin{array}{l}0.50\ Na_2O\\0.45\ ZnO\\0.05\ CoO\end{array}\right\}\left.0.30\ B_2O_3\right\}\ 1.4\ SiO_2$$

These were each intimately mixed and ground in small ball mills, fused, quenched in water, dried and ground to pass 80 mesh sieve.

The four corner glazes were ground wet until they passed 120 mesh sieve, and the remaining glazes blended from them in molecular proportions.

The glazes were applied to two sets of biscuit tile by dipping, and burned to cone 3 in 5 hours in a round, down-draft, open-fired oil kiln. The fires were put out when the finishing temperature was reached and the kiln allowed to cool with the damper closed.

The results were not satisfactory, as only a few crystalline patches appeared. These patches increased noticeably as the content of ZnO increased. High ZnO also appeared to give a deeper blue as would be expected. E 3 showed the most crystallization.

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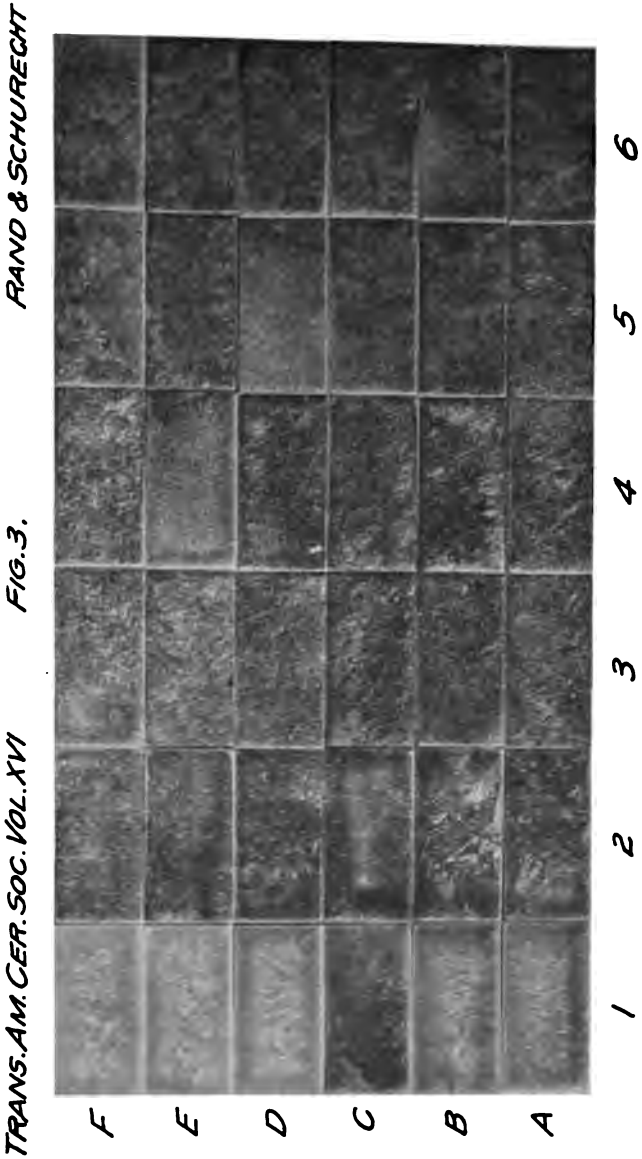

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The failure to obtain good results was attributed to too rapid cooling, too thin coating of the glaze, and perhaps slight under burning.

Next two sets of trials were dipped, care being taken to obtain a thick coating of the glaze, and burned in the same kiln to cone 4, following the heating and cooling curve shown in Figure 2. The pyrometer showed a temperature of 1170°C, when cone 4 went down.

From a crystallization standpoint, the results, Fig. 3, were highly satisfactory. Every glaze showed a large number of crystals and in many cases was a solid mass of crystals of varying sizes. The variation of ZnO and Na_2O seems to have little, if any, effect upon either crystallization or color.

Increase in TiO_2 has a marked effect upon both. As TiO_2 increased the crystals became smaller, and more numerous, most of the high rutile glazes consisting of a mass of small interlocking crystals. At 0.0 TiO_2 and at 0.1 TiO_2, a good blue color is shown, but from 0.1 TiO_2 up, the blue is partially and in some cases almost totally absent. Bronze patches are quite prominent, due possibly to iron impurities in the rutile.

The two sets of trials are very nearly identical. Glaze E 3, with the formula

$$\left.\begin{array}{l} 0.30\ Na_2O \\ 0.65\ ZnO \\ 0.05\ CoO \end{array}\right\} \left\{\begin{array}{l} 0.05\ Al_2O_3 \\ 0.30\ B_2O_3 \end{array}\right\} \begin{array}{l} 1.8\ SiO_2 \\ 0.2\ TiO_2 \end{array}$$

again appears to contain the most crystals and for this reason was selected as the glaze to use in making draw trials with a view to noting different stages of crystallization.

The glazes were dipped and burned in the same manner as before, a number of trials of E 3 being placed where they could be drawn. One was drawn at the finishing point, and one every 20° as the cooling progressed. The third trial drawn showed crystals around the edges. The amount of crystallization increased steadily for four trials. The next trial at 1030°C showed a very great increase, the glaze consisting of a mass of crystals. It is posible that this is due to the crystallization of an eutectic.

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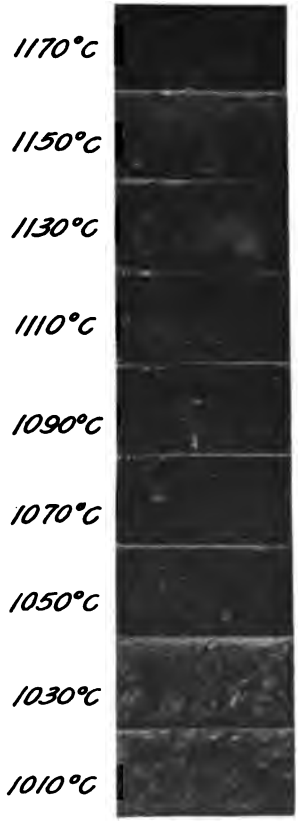
That is, the compound forming the crystals shown first continued crystallizing out until the melt reached the composition of the eutectic mixture, when the whole mass crystallized. (Fig. 4.)

TRANS. AM. CER. SOC. VOL. XVI FIG. 4. RAND & SCHURECHT



One set of trials was placed on edge in this last burn. They failed to show as much crystallization as those lying down, as the glaze had run off to a great extent. However, good results were obtained on two small vases to which the glaze had been applied in a very thick coat, though here also, much of the glaze had been lost.

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COLORED PORCELAIN GLAZES AT CONE 10

BY E. T. MONTGOMERY AND I. A. KRUSON, ALFRED, N. Y.

In taking up the subject of colored or stained porcelain glazes, we must first give consideration to the clear, colorless glaze to be used as the base. The writers have chosen cone 10 as the maturing temperature of this base glaze as being most representative of American practice in porcelain manufacture.

The porcelain glaze corresponding to the cone 4 formula,

$$\left.\begin{array}{l} 0.3\ K_2O \\ 0.7\ CaO \end{array}\right\} \quad 0.5\ Al_2O_3 \quad \{ \quad 4.0\ SiO_2$$

is not a suitable glaze for the work at hand for two reasons. First, it does not mature satisfactorily below cone 12, and second, it is so viscous that the surface, though bright, is found upon close examination to be egg-shelled, due to entrapped gas bubbles. It will be found upon examination under the microscope, that all porcelain glazes of this type, having only K_2O and CaO as fluxes, are full of gas bubbles due to high viscosity from the large amount of feldspar present. This condition is very nicely shown in the photomicrograph of glaze No. 1.

To develop a commercially satisfactory glaze at cone 10 from this type formula, both the maturing temperature must be reduced, and the bubbles eliminated as far as possible. How this is accomplished is shown in the following four glazes and their accompanying photomicrographs.

Glaze No. 1:

$$\left.\begin{array}{l} 0.3\ K_2O \\ 0.7\ CaO \end{array}\right\} \quad 0.4\ Al_2O_3 \quad \} \quad 3.8\ SiO_2$$

This glaze matures at cone 10 to a beautiful glaze of high luster, but contains a great quantity of large bubbles. Figure 1.

Glaze No. 2:

$$\left.\begin{array}{l} 0.3\ K_2O \\ 0.6\ CaO \\ 0.1\ ZnO \end{array}\right\} \quad 0.4\ Al_2O_3 \quad \{ \quad 3.8\ SiO_2$$

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In this glaze we have the bubbles slightly decreased in number and size by adding 0.1 ZnO, which lowers the viscosity of the glaze somewhat. Figure 2.

Glaze No. 3:

$$\left.\begin{array}{l} 0.30\ K_2O \\ 0.55\ CaO \\ 0.05\ Na_2O \\ 0.10\ ZnO \end{array}\right\}\ 0.4\ Al_2O_3\ \left\{\begin{array}{l} 3.7\ SiO_2 \\ 0.1\ B_2O_3 \end{array}\right.$$

By the introduction of borax into the glaze, the viscosity is lowered still further, and therefore, there are fewer and much smaller bubbles. Figure 3.

Glaze No. 4:

$$\left.\begin{array}{l} 0.25\ K_2O \\ 0.55\ CaO \\ 0.10\ Na_2O \\ 0.10\ ZnO \end{array}\right\}\ 0.30\ Al_2O_3\ \left\{\begin{array}{l} 3.0\ SiO_2 \\ 0.2\ B_2O_3 \end{array}\right.$$

In this glaze by the further increase of borax and the reduction of the Al_2O_3 and SiO_2, we reach a commercial, cone 10 glaze, practically free from bubbles. Figure 4. Had this glaze been fired in a 48 hour burn in a commercial kiln, the photomicrograph would have shown almost no bubbles.

As a base glaze for the present work on colored porcelain glazes, glazes No. 1 and No. 2 were used. Glaze No. 2 was used in most cases except where the ZnO would be injurious to the color; and often both No. 1 and No. 2 were tried as base glazes to test the effect of ZnO on a given coloring oxide. All glazes were raw glazes, applied to thoroughly dry green ware and fired in one burn to cone 10.

The investigation was roughly divided into three parts. The first part deals with the colors produced in a cone 10 porcelain glaze by the ordinary coloring oxides, and the amount of the various oxides necessary to produce a satisfactory color. The second part deals with the production of certain commercially desirable colors; and the third part with the investigation of the possibility of producing some of the more unusual colors in a porcelain glaze by the use of the rarer elements, fritted stains or calcined color bodies, etc.

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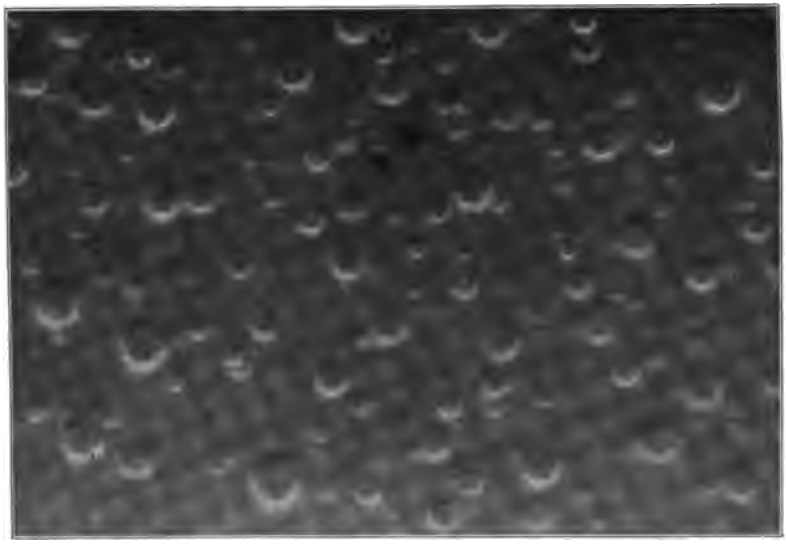

FIG. 1

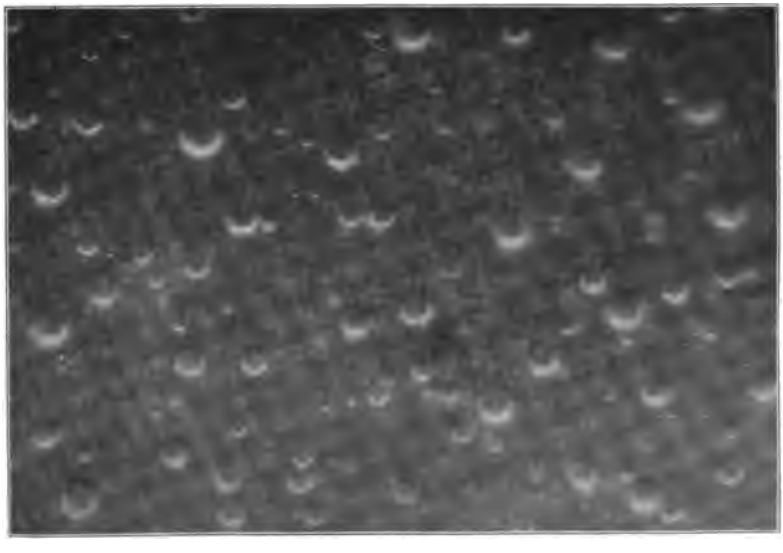

FIG. 2

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PART I

Colors from CoO: We find that 0.025 CoO gives a fine strong light blue, and that increasing depth of color is obtained up to 0.10 CoO which in a good thick dip gives a very deep rich cobalt blue, as dark as one would ever wish to use.

Colors from CuO: 0.125 CuO gives a very pale, delicate copper green. 0.150 CuO and 0.20 CuO give greens of a little deeper shade, but the color is rather feeble and uneven through volatilization.

Colors from MnO_2: 0.1 MnO_2 and 0.15 MnO_2 will practically all burn out. 0.25 MnO_2 gives a fairly deep manganese violet brown.

Colors from Cr_2O_3: In glaze No. 1 containing no zinc, 0.015 Cr_2O_3 produced a light chrome green and 0.15 Cr_2O_3 a very dark chrome green.

Colors from Fe_2O_3: 0.025 Fe_2O_3 produces practically no color in the glaze, 0.05 Fe_2O_3 gives a pleasing light tan, and 0.10 Fe_2O_3 gives dark olive tan or brown.

Colors from burnt umber: This coloring agent gave the same colors as Fe_2O_3, but lighter in tint where substituted for Fe_2O_3, due to its lower Fe_2O_3 content.

Colors from the yellow oxide of uranium ($Na_2U_2O_7 + 6H_2O$): 0.01 U_2O_3 gives a very pleasing light lemon yellow, and 0.02 U_2O_3 gives a slightly darker yellow. An increase to 0.06 U_2O_3, which is equivalent to about ten percent of oxide in the glaze batch, gives only a slight increase in depth of color.

Colors from NiO: 0.05 NiO gives a light, pleasing nickel-brown; 0.10 NiO gives a darker medium brown; and 0.15 NiO gives a very rich dark nickel brown.

PART II

Having shown the colors produced by the single oxides which are commonly used, we will now take up the production of the colors most often called for in commercial practice. In discussing this part of the work, only the glaze batches will be given as being more exact, since there is no uniformity of practice in figuring coloring oxides into a formula.

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FIG. 3

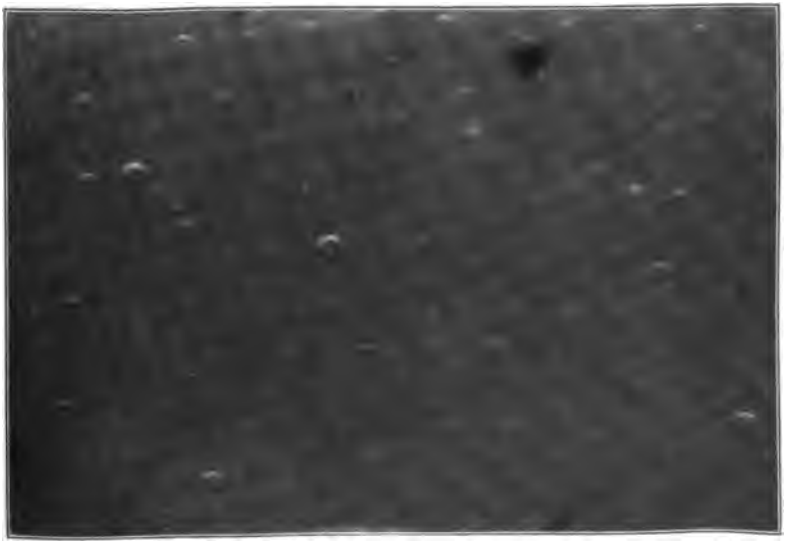

FIG. 4

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TABLE I—BLACK GLAZES

	6A	6B	9A	9B	9C	9D	10A	10B
Feldspar	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0
Whiting	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
ZnO	2.0	2.0	0.0	0.0	0.0	0.0	1.0	1.0
$BaCO_3$	0.0	0.0	2.0	2.0	2.0	2.0	0.0	0.0
MnO_2	2.0	0.0	2.0	0.0	2.0	0.0	2.0	4.0
CoO	1.3	1.6	1.3	1.6	2.5	1.3	1.3	1.3
Cr_2O_3	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0
Fe_2O_3	2.0	2.0	2.0	2.0	1.0	2.0	5.0	2.0
Ball clay	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Borax	8.0	8.0	8.0	8.0	8.0	8.0	7.0	8.0
Flint	20.7	22.4	20.7	22.4	20.5	21.7	19.7	19.7
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Glaze 6A is not a good black but is a very dark chocolate brown—almost black. Glaze 6B is a very good black with a slight brownish cast as differentiated from a greenish or bluish black. Glazes 9A and 9B are the same as 6A and 6B, except that the ZnO is replaced by BaO, thus eliminating the effect of ZnO on the Cr_2O_3 present. We get, in both 9A and 9B, beautiful deep blacks similar to 6B, but richer in tone and without a certain grayish cast noticeable in 6B in certain lights. Glaze 9C is a perfect jet black without a cast of green, blue or brown. Glaze 9D is a fine black but with a slight greenish cast. Glaze 10A is a very handsome deep seal brown in a strong light, and 10B is a fine deep black very similar to 9C.

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TABLE II—GREEN GLAZES

	7A	7C	7B	7D
Feldspar	45.0	45.00	45.0	45.0
Whiting	12.0	12.00	12.0	12.0
CoO	0.0	0.75	1.5	2.0
Cr_2O_3	6.0	4.00	2.0	1.5
MnO_2	0.0	0.00	0.0	3.0
Ball clay	8.0	8.00	8.0	8.0
Borax	10.0	10.00	10.0	10.0
Flint	22.0	22.00	22.0	22.0
	103.0	101.75	100.5	103.5

Glaze 7A is a typical, deep, olive chrome-green; 7C is a rich grass green; 7B is a fine blue green or myrtle green; and 7D a very dark "coach green," bordering on a black.

Brown Glazes: The following is typical brown Albany slip insulator glaze:

Glaze No. 19:

Albany slip	46.5
Feldspar	37.2
English ball clay	9.3
Burnt umber or Fe_2O_3	4.7
Borax	2.3
	100.0

Fine browns can be made with NiO alone. Glaze No. 21 is a seal brown or dark coffee color; No. 21A is a fine dark brown, a little darker than No. 21, and No. 15 is a rich dark mahogany brown.

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TABLE III—BROWN GLAZES

	No. 21	No. 21A	No. 15
Spar	42.3	42.0	42.0
Whiting	12.6	13.0	15.0
ZnO	2.6	2.0	2.0
MnO_2	1.7	2.0	2.0
$CoCO_3$	0.0	0.0	0.6
NiO	0.0	2.0	0.0
Cr_2O_3	1.0	1.0	1.0
Fe_2O_3	2.0	2.0	1.6
Ball clay	8.2	8.0	4.2
Borax	8.0	8.0	8.0
Flint	21.6	20.0	23.6
	100.0	100.0	100.0

TABLE IV—SLATE-COLORED GLAZES

	18A	18B	18C	18D	18F
Feldspar	44.0	44.0	44.0	44.0	37.0
Whiting	15.5	15.5	15.5	15.5	19.0
ZnO	2.1	2.1	2.1	2.1	0.0
CoO	0.2	0.4	0.6	1.0	0.0
$CoSO_4$	0.0	0.0	0.0	0.0	0.8
Fe_2O_3	1.7	0.0	0.0	4.0	1.7
U_2O_3	0.0	4.0	6.0	0.0	0.0
Ball clay	6.8	6.8	6.8	4.0	16.0
Flint	30.0	30.0	30.0	30.0	25.5
	100.3	102.8	105.0	100.6	100.0

Glaze 18A is a very light pleasing slate color; 18B is a little darker slate; 18C still darker; and 18D a very dark slate. Glaze 18F is a very pleasing medium slate color.

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PART III

The coloring power of chemically pure titanium oxide, TiO_2, and of rutile, in a porcelain glaze was investigated. Five percent of C. P. TiO_2 added to base glaze No. 1 gave only a slight yellowish cast, and ten percent gave a slightly deeper straw color. The addition of five percent of rutile gave a pleasing light corn-flower yellow, while ten percent gave a similar but deeper yellow.

Beautiful opaque white enamels were made by the addition of eight to ten percent of tin oxide, SnO_2, to base glaze No. 2.

Platinum blacks, and blacks from reduced uranium oxide were also investigated. For platinum blacks the following solution of platinum chloride was used.

Black No. 1

Platinum chloride	0.5
Blue No. 1 solution	1.0
Glycerine	1.5
Dextrine solution	2.5

Blue No. 1

Cobalt nitrate	4.0
Glycerine	3.0

Dextrine Solution

Water	30 c.c.
Dextrine	20 Grs.

Five drops of solution, Black No. 1 to one gram of base glaze No. 1 gave a fine steel grey, and ten drops of the same solution to one gram of glaze gave a beautiful greyish black.

In the production of uranium blacks, two methods were used. Glazes containing 0.04 to 0.06 equivalents of uranium oxide, about eight to ten percent, gave fine brilliant jet blacks, when fired under reducing conditions. Blacks from uranium were also attempted in a regular oxidizing burn by using ten percent of a uranium underglaze color-body of the following composition: $1.0\,UO_2(NO_3)_2 \cdot 6\,H_2O + 1.0$ kaolin, which had been previously reduced in calcining, as a stain in base glaze No. 1. Yellow glazes resulted, mottled with grey or black where the glaze was thickest. This same color-body gave a good black as an underglaze color in another investigation.

Pinks were developed from a variety of sources. Very light to very deep chrome-tin pinks were produced by adding to base

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glaze No. 1 increasing percents of the ordinary Seger pink up to ten percent.

Chrome-alumina pinks were attempted by adding to base glaze No. 1, five percent and ten percent of several different underglaze color-bodies. The only one which gave a pink color was the following:[1]

$$\left.\begin{array}{l} 0.046\ K_2O \\ 0.658\ MgO \\ 0.296\ ZnO \end{array}\right\} \left.\begin{array}{l} 0.722\ Al_2O_3 \\ 0.046\ Cr_2O_3 \end{array}\right\} 0.08\ B_2O_3$$

This color was calcined at cone 14 and then washed. Five percent of it added to glaze No. 1 gave a light greenish color, ten percent produced a quite pleasing salmon pink but so over-loaded the glaze with Al_2O_3 that the surface was dull.

Manganese-alumina pinks were produced by adding to base glaze No. 1, five, ten and fifteen percent of the following color body:

		Batch	
1.00 Equivalent	$Al_2O_3.3H_2O$	156.00 gr.	$Al_2O_3 . 3 H_2O$
0.15 Equivalent	$MnSO_4.4H_2O$	33.45 gr.	$MnSO_4 . 4 H_2O$

Calcined at cone 07 and washed. This color gives a very beautiful bright pink with five percent and ten percent added to the glaze. Fifteen percent of color over-loads glaze No. 1 enough to dull the surface. The glaze would have to be softened by the addition of borax to permit the use of this much color.

Very delicate flesh-colored pinks were also produced by the use of the following gold chloride solution:

Pink No. 1

Chloride of gold	0.5
Glycerine	6.0
Dextrine solution	6.0

From five to ten drops of this solution added to one gram of base glaze No. 1 will give a fine delicate pink.

The writers were also interested to see, if the blue and purple colors from nickel reported by Pence[2] could be produced in a

[1] Volume XI. *Trans. Amer. Cer. Soc.*, page 56.
[2] *Trans. Amer. Cer. Soc.*, Vol. XIV, page 143.

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porcelain glaze. Accordingly the following glazes were made up, using the content of ZnO which he found necessary to produce the purple and blue colors. As a low content of NiO did not seem especially necessary in Mr. Pence's work, a sufficient amount was used to give a deep color if the purple or blue were produced. It was also thought that the higher Al_2O_3, and higher SiO_2 content especially, might require more NiO.

Glaze No. 16 C (for a purple)

$$\left.\begin{array}{l} 0.30\ K_2O \\ 0.25\ ZnO \\ 0.45\ CaO \\ 0.15\ NiO \end{array}\right\}\ 0.4\ Al_2O_3 \quad \{\ 3.8\ SiO_2$$

Glaze No. 16 D (for a blue)

$$\left.\begin{array}{l} 0.30\ K_2O \\ 0.40\ ZnO \\ 0.30\ CaO \\ 0.15\ NiO \end{array}\right\}\ 0.4\ Al_2O_3 \quad \{\ 3.8\ SiO_2$$

Both resulted in dark nickel browns. Four other glazes were therefore made up using the same RO as used by Mr. Pence, instead of the usual RO of the porcelain glaze. As low a NiO content was also tried as would produce a color at cone 10.

Glazes No. 16 E and No. 16 G (for a purple)

$$\left.\begin{array}{l} 0.25\ K_2O \\ 0.20\ CaO \\ 0.30\ BaO \\ 0.25\ ZnO \end{array}\right\}\ 0.4\ Al_2O_3 \quad \{\ 3.8\ SiO_2$$

For No. 16E, 0.15 NiO was added to the above glaze, and for No. 16G, 0.05 NiO was added.

Glazes No. 16 F and No. 16 H (for a blue)

$$\left.\begin{array}{l} 0.25\ K_2O \\ 0.14\ CaO \\ 0.21\ BaO \\ 0.40\ ZnO \end{array}\right\}\ 0.4\ Al_2O_3 \quad \{\ 3.8\ SiO_2$$

For No. 16F, 0.15 NiO was added to the above glaze, and for No. 16H, 0.05 NiO was added. All four gave nickel browns.

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Conclusion. It has been demonstrated that a great variety of colors can be produced in a porcelain glaze at cone 10. There are a few general conclusions which may be drawn from this work as follows:

Borax may be advantageously added to a raw porcelain glaze in amounts up to ten percent without causing any difficulty in the application of the glaze.

Tin oxide must not be used with Cr_2O_3 in a glaze where greens are expected.

DISCUSSION

Mr. Watts: I should like to ask Mr. Montgomery, in connection with the use of borax, what his particular object was in introducing borax into the glaze. Was it your intention Mr. Montgomery to get the softening effect of the soda in addition to the B_2O_3?

Mr. E. T. Montgomery: Yes, it was done chiefly to get an active flux. This material was used particularly, because borax is very efficient in reducing viscosity. By the use of borax, we eliminate bubbles; and it also gives a higher gloss and a glaze of a lower maturing temperature.

Mr. Watts: Would you not have gotten the same effect with a somewhat softer feldspar? I do not know what you are using, but I should think that you could have introduced B_2O_3 in the form of boric acid, instead of borax, and thus eliminated this soluble soda. Or would that not have done the same work?

Mr. E. T. Montgomery: A softer feldspar would not eliminate bubbles. I have not tested the point in regard to the use of B_2O_3. I suppose that boric acid would act as a flux just as well as a corresponding amount of borax, but I used borax because it is the commercial practice to do so. I have not even investigated the question of cost. We know that borax is used more commonly for the introduction of Na_2O, and probably would be the cheaper material to add and is no more soluble than boric acid.

Mr. Watts: Cheaper than boric acid?

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Mr. E. T. Montgomery: It is cheaper, I believe, than we could get the same amount of fluxing action by introducing Na_2O and B_2O_3 in any other forms.

Mr. Watts: I had in mind the use of B_2O_3 which I have always added in such glazes as this in the form of boric acid, leaving my alkalis all to be added from feldspar. I did this because of the fact that it is very often necessary in actual practice to take some water off your glaze, and the introduction of a lot of soluble salts into your glaze causes the glaze to be more or less variable. At least that was my experience. Regarding the introduction of B_2O_3 in cone 10 glazes, I have always imagined (and I justified my imagining by chemical investigation) that the B_2O_3 did not remain in the glaze to any appreciable extent after about cone 7—at least I could not get any evidence of it in the glaze after it was past that point. I concluded that the efficiency of B_2O_3 in the glaze was that of a low temperature flux, which caused the glaze to remain smooth and viscous on the surface of the body, while the enormous shrinking was taking place, that occurs between cone 3 and about cone 7 in porcelain bodies as they begin to vitrify. I found that the glazes, that did not contain a certain amount of B_2O_3 had a tendency to give an unsatisfactory surface, and that B_2O_3 was valuable in helping the glaze through that particular period, during which that shrinkage occurs. I never use borax in any hard glaze. I have experimented with it once or twice, but was never satisfied that I could afford to add my soda in that form. I could get any desired amount of soda in the form of rather soft feldspars.

While I am on my feet I should like to mention the proposition of brown glaze. Is this mahogany-brown glaze similar to that obtained by the use of Michigan slip?

Mr. E. T. Montgomery: I should say not. You would get a variable glaze by the use of that, the same as you do with Albany.

Mr. Watts: In 1900 or about that time, when I first became acquainted with the insulator industry, the Michigan slip began to be introduced and was used in increasing amounts to replace the Albany; so that it occurred to me that if you are

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going to use iron as a coloring, it would be advantageous to introduce the iron into the glaze in one of these slip forms, or in the form of *crocus martis* or something of that sort, rather than as commercial Fe_2O_3.

Mr. E. T. Montgomery: I do not know that there would be any advantage only that it would enter into combination more quickly.

Mr. Watts: It would be more finely divided; and as long as you were not going to have an absolutely opaque enamel such as you get with Cr_2O_3, I imagine that you would get a more satisfactory color by adding the iron in a more finely divided state, as in the form of an iron bearing clay. That was, as you know, the general practice formerly; although there are some manufacturers who are especially fond of dark brown opaque glazes. For instance, the General Electric Company has for years used a brown-black almost a black glaze on its high tension insulators; but the high tension insulator field calls for mahogany-brown glaze, and whether or not you could introduce a completely opaque brown-black glaze, would rest entirely with the electrical engineer. That would not always match up with his ideas of what he wants in the way of a glaze.

My experience was that the electrical engineer was rather a difficult man to deal with. On introducing the slate insulator glaze in 1905, I know what a time I had to get the electrical engineers in the country to begin to use a slate-colored glaze, and by the time I had them educated to the point that they were willing to do so, I realized what a calamity that I had brought on myself by creating a demand for two different stocks, one mahogany-brown, the other slate-colored, whereas they were formerly satisfied with one color, mahogany-brown. This meant keeping a double stock where they were formerly satisfied with one. Whether you could get an electrical engineer to shift from a standard mahogany brown glaze that is semi-clear, very much like the old-fashioned Rockingham brown glaze, only a little more reddish and a little darker, is a question. I do not mean to say that these glazes are not practical for insulator glazes, because I believe that many of them are infinitely more practical,

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than those used to-day by the insulator people; but the question is whether when you switch them around once or twice they will not get tired of being switched.

Mr. E. T. Montgomery: I want to ask Mr. Watts whether the mahogany-brown glaze prepared from Michigan slip is uniform. Can you produce throughout the kiln as uniform a color with it as you can get by compounding a glaze without the use of slips?

Mr. Watts: You cannot get a uniform color in any iron bearing glaze, with any slip. The uniformity of color which you can get with an opaque glaze is far in advance of anything that you can get with one that is not absolutely opaque, so you cannot expect to get that uniformity of color with the Michigan slip.

Mr. E. T. Montgomery: My idea was that the old form of Michigan slip glaze had gone out of existence. That the General Electric Company have been for years using the dark almost black mahogany-brown, would indicate that they are finding it satisfactory. It is certainly infinitely better in appearance, than any slip glaze that I have ever seen; and that is surely the direction in which we are going and is a distinct improvement over what we had in the past.

Mr. Minneman: I should like to ask Mr. Montgomery whether he has noted any difference in the color of those samples such as he would get in commercial practice from one part of the kiln against those from another part; and also whether these chromium greens show a difference with different temperatures or kiln conditions?

Mr. E. T. Montgomery: I have not carried out these studies as extensively as that, and cannot therefore answer the questions regarding differences caused by the location in the kiln.

Mr. Back: I should like to ask Mr. Montgomery, the source of the nicked he used in obtaining the nickel blues.

Mr. E. T. Montgomery: I did not obtain any.

Mr. Back: You attempted it.

Mr. E. T. Montgomery: Mr. Pence used commercial green nickel oxide and also C. P. oxide which he prepared himself from absolutely C. P. materials. He was able to get the blues and the

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purple color, at the low temperatures which he used, from nickel oxide from both sources; and there was very little difference, he reports, between the colors.

Mr. Back: I asked this question because of some work that I did with some crystalline glaze mixtures of zinc, lithium and silica. I obtained some turquois blue color apparently due to iron. It is difficult to obtain nickel salts and minerals, free from iron; and whether the color was due to the nickel or iron impurity is a question in my mind. The glazes were fritted at quite a high temperature in a crucible heavily lined with silica, and the silica lining was worn away in the hole at the bottom of the crucible, so that some of the iron of the crucible dissolved out. This may have produced the color. To determine whether it was at all possible, that the alumina had anything to do with the result, I pushed an iron rod down into the surface of the melt where there was no opportunity for the melt to come in contact with the contents of the crucible. I found a deep blue glaze adhering to the iron rod.

Mr. E. T. Montgomery: We do get blues under certain conditions from iron. Mr. Pence answered your question very fully in the paper of last year, and showed that there was no chance in the production and use of the C. P. oxide for the coloring to come from anything but the nickel oxide.

Mr. McDougal: I should like to refer to a statement that Mr. Montgomery made and to suggest that although he did not run into trouble with as high as ten percent of borax which is a soluble salt in this glaze, he might do so in another type of glaze which might differ in its raw clay content. The soluble salt would likely affect the physical properties of the glaze, if the slip mentioned before this were applied.

Mr. Watts: I should like to say one other word. I made some rather extensive investigations regarding the use of boric acid in that hard glaze for the purpose of ascertaining whether the exact amount of boric acid was right. I found that I got the same effects, the same amount of gloss, and the same uniformity of color, in glazes with a considerable range of boric acid in the glaze, provided always that I had at least 0.05 of an equivalent

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of boric acid in the glaze. That enabled me, if necessary, to tap some water off my glaze, if I wanted to have my glaze a little thicker, and not seriously injure it. I found that this was quite a convenience, because if I introduced soda with the borax I would not have dared juggle the B_2O_3 content as I could under the other condition. I did not find the actual content of B_2O_3 to be vital in the glaze.

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REPORT ON RATTLER TESTS MADE ON BRICK OBTAINED FROM PAVED STREETS[1]

BY G. H. BROWN

Since the introduction of the rattler in the testing of paving brick, there has been considerable difference of opinion, first, as to the relation of the behavior of paving brick in the rattler and in actual service, and, second, as to the allowable limits of percentage losses in the rattler test. It has been contended that low rattler losses do not necessarily indicate high class behavior in service, and that the maximum rattler losses allowed in specifications are in many cases too low.

The introduction of the new standard rattler adopted by the National Paving Brick Manufacturers Association was found to have increased somewhat the severity of the rattler test, and increased agitation of the question followed.

Two methods of comparison of the behavior of paving brick in the rattler test and in actual service suggested themselves—the first, to lay sections of streets from paving brick whose behavior in the rattler is known and await a period of years to observe their behavior in service. The second—to select brick which have been in service in streets for a number of years and subject them to the rattler test. The latter method was adopted, as the former method of procedure would involve tedious waiting. Offers of coöperation having been secured from the Board of Public Works and Engineers of a number of cities, an investigation was undertaken according to the following general plan.

1. Samples were taken from brick paved streets which had been in service from five to twenty years. In selecting the streets from which the samples were taken, it was planned to secure brick which in some cases had given good service and brick whose quality and service had been doubtful or unsatisfactory.

2. When possible, an average sample of 200 brick was taken, the cut being made so as to include a section of the street extending from the center line to curb, or from car track to curb.

[1] By permission of the Director, National Bureau of Standards.

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If a sample of this kind could not be secured the brick were selected in connection with street repairs.

3. In cutting and removing the sections, observations were noted as to the nature, uniformity of application, and condition of the bonding material between the bricks, of the character and amount of the cushion material, and as to the nature and condition of the foundation of the street.

4. From the reports and files of the city, all possible data as to the date of the construction of the street, the brand of brick, specifications under which the street was laid, and the results of rattler tests, if any, were obtained.

The samples were prepared for testing at the laboratory. Bricks, held together in coherent sheets by cement grouting, were separated, by chiseling. The adhering cement was carefully removed from the sides and depressions of the individual bricks. As most of the preparation for testing was carried out in cold weather, it was found that the adhering tar fillers could also be removed by chiseling. The depth of wear and general condition of each brick was noted. Samples excessively worn or broken in the cleaning process were discarded.

Rattler Test. Before testing, all brick were dried in a gas drier at 110°C.

The tests were made in a standard rattler constructed and operated under the specifications of the National Paving Brick Manufacturers' Association.

A condensed statement of the results of the investigation is shown on the chart, the results of the tests being arranged in order of the percent losses in the standard rattler. The average rattler losses were secured from eight to ten rattler tests on each brand of brick.

Presented in this manner, the bricks tested may be divided into three groups:

Group No. 1, including samples Nos. 1 to 8, whose rattler losses range from 15.5 percent to 22.0 percent, and all of which have given more or less excellent service in streets.

Group No. 2, including samples Nos. 9 to 13, whose rattler

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TABLE

NO.	AVERAGE RATTLER LOSS PERCENT	SERVICE YEARS	TRAFFIC	FILLER	FOUNDATION	CONDITION OF BRICK	MATERIAL	CITY
1	15.50	17	Medium heavy	Tar	4 in. sand 8 in. stone	Excellent	Fire clay	Columbus
2	17.58	19	Medium	Cement	1 in. sand 6 in. concrete	Excellent	Calcareous	Buffalo
3	17.81	15	Medium	Cement	1 in. sand 6 in. concrete	Excellent	Fire clay	Syracuse
4	18.31	19	Heavy	Cement	1 in. sand 6 in. concrete	Excellent	Calcareous	Syracuse
5	18.39	14	Medium to heavy	Tar	2 in. sand 6 in. concrete	Excellent	Shale	G. Rapids
6	20.52	18	Medium	Cement	2 in. sand 6 in. concrete	Excellent	Shale	Sandusky
7	21.94	11	Heavy	Cement	2 in. sand 6 in. concrete	Fair	Shale	G. Rapids
8	22.11	10	Medium	Tar	2 in. sand 6 in. concrete	Fair	Shale	Cincinnati
9	23.28	19	Medium to heavy	Cement	2 in. sand 6 in. concrete	Poor	Fire clay Shale	Sandusky

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10	23.49	17	Medium to heavy	Tar	4 in. sand 8 in. stone	Very poor	Shale	Columbus
11	23.74	14	Light	Cement	Sand	Excellent	Fire clay	Cleveland
12	24.01	6	Medium to heavy	Cement	6 in. concrete 2 in. sand	Excellent	Shale	Cleveland
13	26.91	12	Medium	Tar	3½ in. sand 4 in. concrete	Fair	Shale	Cincinnati
14	27.43	17	Medium	Cement	Sand	Poor	Shale	Albany
15	29.31	5	Medium	Cement	2 in. sand 6 in. concrete	Failing	Fire clay	Toledo
16	31.44	6	Medium to heavy	Cement	1 in. sand 6 in. concrete	Complete failure	Fire clay	Buffalo
17	37.88	19	Medium	Cement	1 in. sand 6 in. concrete	Complete failure	Shale	Rochester
18	38.88	18	Medium	Cement	1 in. sand 6 in. concrete	Complete failure	Fire clay	Rochester

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losses range from 23 percent to 27 percent, and whose service in streets has in some cases been excellent and in others poor.

Group No. 3, including samples Nos. 14 to 18, with rattler losses of 27 percent and greater. In this group failure under the traffic conditions has taken place in every case.

At this point it must be emphasized that variation in the type, and in the degree of excellence of construction occurs in each of the three groups.

In group 1 we have both tar and cement fillers, concrete and broken stone foundations, and variations in the thickness of the sand cushion.

In group 2 both tar and cement fillers were used, and sand, broken stone and concrete foundations.

In group 3 with cement filler, sand and concrete foundations occur.

In each group, variations in the strength and quality of construction and application of the foundations and bonding materials, occur.

An interesting comparison may be made between Columbus, Ohio, samples numbers 1 and 10, the former having a rattler loss of 15.50 percent, and the latter 23.49 percent. The sections were taken from adjacent points in the same street and were laid under one specification at the same time and by the same contractor. At the time of removal, the portion of the street laid from sample No. 1, rattler loss 15.5 percent, was in excellent condition, while the portion constructed from sample No. 10, rattler loss 23.49 percent, was in very poor condition.

Samples 2 and 4 in group 1, showing rattler losses of 17.58 percent and 18.31 percent were manufactured from a calcareous clay. In selecting these bricks for street paving, the engineers stated that only hard burned bricks or bricks having high shrinkage were placed in the streets. As a result an extremely hard and uniform product was secured, and good service resulted. These bricks were at a disadvantage in the rattler tests, their dimensions being less than those of an ordinary building brick.

Brick samples Nos. 6 and 9 having rattler losses of 20.52 percent and 23.28 percent afford another interesting comparison.

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The sections were taken from two streets in Sandusky, Ohio. Considering the service, the street from which sample No. 6 was taken was in better condition, than any of the brick streets inspected. On the other hand the street from which sample bricks No. 9 were taken was in poor condition.

Samples Nos. 11 and 12, having rattler losses of 23.74 percent and 24.01 percent have given excellent service.

Without exception, samples 14 to 18, having rattler losses of 27 percent and greater, have given very poor service.

The variation in quality of service of group 2, samples 9 to 13 inclusive, is attributed to variation in the type and quality of construction.

Conclusion. In conclusion, we may state that in this series of tests, bricks, having a rattler loss of 22 percent and less, have given comparatively excellent service under several types of construction. Bricks showing rattler losses from 23 percent to 27 percent appear to have given both excellent and indifferent service, the degree of excellence being governed by the nature of the construction. Bricks showing rattler losses of 27 percent or greater have failed in every case apparently, regardless of construction.

Next to the inherent good qualities of the paving brick, proper construction is of paramount importance. As previously stated, the primary object of this investigation was to endeavor, first to determine the value of the rattler test in measuring the ability of paving brick to withstand the action of street wear; and, second, to establish the permissible limits of the losses of paving brick in the standard rattler. Although, in this series of tests, brick of high rattler losses have failed apparently, regardless of construction, the life of a street laid from bricks of low rattler losses is bound to be indefinitely increased by careful and approved construction.

In answer to the question as to whether paving brick manufactured in this country today are superior or inferior to those manufactured 15 or 20 years ago, a comparison of this series of rattler tests on old brick, with a series of 14 brands of present day brick, recently tested in the new rattler, shows about the

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same range of rattler losses. The minimum loss of the new brick was 16 percent, and the maximum losses averaged 39 percent, with about the same gradation as reported in this investigation.

Thanks are due Prof. Edward Orton, Jr., for suggesting an investigation of this kind and assistance in outlining the procedure, and to Prof. A. V. Bleininger for helpful suggestions and assistance.

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RECENT DEVELOPMENTS AND IMPROVEMENTS AT THE NEW YORK STATE SCHOOL OF CLAY WORKING AND CERAMICS

BY E. T. MONTGOMERY, ALFRED, N. Y.

With the exception of the Ceramic Department of the Ohio State University, which a large majority of our members have visited and know quite thoroughly, the Ceramic Departments and Ceramic Schools of the country are so located in the seclusion of small college towns, that they are but infrequently visited by any except those directly interested in them.

To all but a very few of the members of this Society, I presume the name, "New York State School of Clay Working and Ceramics," at Alfred University, though it is the second oldest ceramic school in the country, means as little in the way of definite, concrete information about the location, organization, equipment, work and aims of this school, as it did to me previous to last August, when I was asked to join its faculty as assistant professor and assistant director of the school.

It has, therefore, seemed fitting to me to bring to the Society some definite information about what the New York State School of Clay Working and Ceramics is, and what it is doing, together with a description of its equipment and the courses of study offered. It has seemed especially fitting to do so just at this time, when its capacity has just been doubled by the expenditure of a special appropriation of 25,000 dollars, in the extension of the building and in the purchase of new equipment; and when its courses of study have just been revised, systematized, broadened and strengthened.

In the year 1900, the president and trustees of Alfred University sought legislation providing for the construction and maintenance of a school of clay working and ceramics in the state of New York. The effort was successful, and the school was founded at Alfred University.

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VIEW OF BUILDING

DRAWING ROOM

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Alfred University is located at Alfred, Allegany County, New York, on the main line of the Erie railroad between New York City and Chicago. It is beautifully situated among the rugged hills of southwestern New York, at an elevation of eighteen hundred feet. The University was founded in 1863—seventy eight years ago. Its university charter was granted in 1857.

Beside the University proper which offers courses in Arts, Philosophy and Science, there are at Alfred, either operated by the University or affiliated with it: Alfred Academy, the preparatory department; the Theological School; the Alfred State School of Agriculture, which is one of six similar agricultural schools within the state, either now in operation or authorized; and the New York State School of Clay Working and Ceramics.

The control of the ceramic school is vested in the trustees of Alfred University, who annually appoint a board of managers consisting of five members.

In July, 1900, immediately following the appropriation of the funds for the work of construction, Professor Charles F. Binns was appointed director of the school, and at once he took up the work of supervising the construction and equipment of the large and substantial brick building especially designed to meet the needs of a clay working and ceramic school.

The original building is built of red face brick with terra-cotta trimmings and a tile roof. It has a frontage of seventy-five feet, and its four floors, all of which are in use, give a total floor space of 13,000 square feet. To this main building has been added this past summer, a two story, modern, fire-proof wing, about 36 feet wide and 57 feet long, at a cost of 15,000 dollars, thus giving the building over 4,000 additional square feet of floor space, as well as much improved kiln and furnace rooms.

The building and equipment of the New York State School of Ceramics, in compactness and completeness of detail, stands to-day second to no other ceramic school or department in this country, and that means second to no other in any country, for the United States is to-day the leader in this field. We shall to-morrow be again eclipsed by the ceramics department at the University of Illinois in size, but I doubt if that will be true in

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View in Kiln Room

View in Kiln Room

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regard to equipment. The new wing has a sub-basement, in which is located the steam heating plant, fuel storage and a large damp cellar. On the main basement floor are located the following rooms: The kiln room contains a gas-fired kiln of about the usual laboratory type, except that it was designed to be fired with gas only, and has no fire box. A coal-fired up and down-draft kiln built from a German model, has a lower compartment or chamber for glost ware fired at a high temperature, and an upper low temperature chamber for biscuit ware. There are also a gas fired muffle kiln having a muffle of a little over one cubic foot capacity and a small size gas-fired Caulkins kiln for enamel work and over-glaze decoration. All kilns are wired to a switch board, which possesses a flexible cord connection to a Siemens and Halske recording galvanometer. A Bristol wall-type indicator is also installed in the kiln room to connect with this switch board when the Bristol pyrometer is in use. Beside the instruments mentioned, the pyrometer equipment consists of Heraeus platinum and platinum-rhodium thermo-couples encased in Norton alundum tubes, another Siemens and Halske millivoltmeter of the portable type, and a Fery pyrometer with one of the Taylor Instrument Company's new indicators. There is a storage room, a room containing a large dry pan for heavy grinding, and a large work room containing most of the heavy machinery. This machinery includes a wet pan, pug-mill, brick machine, repress, roofing-tile press, a heavy screw press which will take any size work up to a dry-press brick, a small Crossley screw-press with floor and wall tile dies a complete Crossley slip room outfit mounted on one base, the filter press of which is pumped up by compressed air, a large grinding cylinder and two smaller ones, Crossley juggers, throwing wheel and lathe, and three medium size agitators for casting slips. There is a fully equipped mold shop with drying room adjoining. On this floor there is also the power equipment, as the school furnishes its own power beside furnishing electrical power to the machine shop and wood shop. This equipment consists of two Otto gas engines of 36 and 8 horse-power respectively, and two Westinghouse generators of 18 K.W. and 3 K.W. capacity, respectively,

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MODELING STUDIO

VIEW IN ART STUDIO

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giving a 110 volt current. There is also an air compressor, furnishing air at any pressure up to seventy-five pounds.

On the first or main floor are located the executive offices; a very complete library of ceramic literature and current ceramic periodicals; a lecture room equipped with lantern and a fully furnished chemical lecture table; a large technical laboratory equipped with work tables containing lockers for each student, balances, ball mills, bucket blungers, a small jaw crusher, a fine pulverizer and a spraying equipment and hood for spray glazing; a locker room equipped with steel lockers for men students; a modern chemical laboratory equipped for thirty-two students, with a balance room adjoining. On the main floor there is also a kiln room solely for the use of the Art Department, equipped with a large Caulkins kiln; and lastly, an up-to-date furnace room equipped with two Seger test furnaces, one Seger muffle furnace, two drop frit furnaces of different sizes, fired with gas and compressed air, a small crucible frit furnace, a large cylindrical furnace of the pot-furnace type for high temperatures, having two burners and fired with gas and air, one platinium wire resistance and one nichrome wire resistance electrical furnace built at the school, and a platinum wire resistance muffle furnace and another crucible furnace. There is also yet to be built a carbon resistance furnace for fusion point tests of refractories.

On the second floor is located the department of Design and Applied Art. This department occupies three large rooms beside its office, which has a special library on art subjects. One room is devoted to drawing and painting, another to charcoal sketching from casts, for which work the studio is well equipped with casts of many famous examples of the sculptor's art, a number of which are full size reproductions. The third room is the modeling studio, fully equipped with casts, models, tools and damp closets for each student.

On the third floor is a large lecture room equipped with a lantern, and a large studio for special and advanced work of the art department.

The New York State School of Ceramics is unique among the other ceramic schools of the country both in the courses of-

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View in Furnace Room

View in Furnace Room

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fered and, to a certain extent, in its methods. It is unique in that it is not only a technical school but an art school as well. This is an ideal arrangement, provided each serves its own purpose and strengthens rather than weakens the other. We are here confronted with the old problem of determining how best to utilize the four years devoted to a college course, when there is six or more years' work which we feel should be done. Previous to this year, the work of the junior and senior years was large y elective, so that many students in the technical course took work in the Art Department to the detriment of their technical training, or took work in the college, that they might satisfy the Regent's requirements of New York State for teachers' certificates, to the detriment of their undivided interest in ceramics and their determination to make it their life work. We have learned through experience that this policy was faulty, and we have, therefore, in this year's catalogue changed these courses to two strong, independent courses, one in technical ceramics and one in art. Each covers a four year period and in each all subjects are required. A short course in the clay working, and a short course in Normal Art are also offered.

The plan of the courses also differs somewhat from those in vogue elsewhere, partly through necessity and partly through policy. Not having an engineering college available, so that other engineering subjects might be added to our course, we are doing the obvious thing—teaching more ceramics, beginning right in the freshman year, and not only that but teaching mathematics and chemistry and physics more thoroughly. I am well aware of the fact that the courses of study in ceramics at the Ohio State University and at the University of Illinois, for example, need no justification, nor do I think that the New York State School of Ceramics in its honorable and efficient record for the past fourteen years needs any justification. The courses as now revised, enlarged and systematized embrace not only the technology of all clay and rock products, but also the artistic manipulation and decoration of such of them as serve an asthetic rather than a utilitarian purpose. We are confident in the expectation that our courses will from this time forward serve in a better and

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View in Main Technical Laboratory

View in Technical Laboratory

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fuller measure, first the people of the state of New York whose judgment and generosity have made the school and its work possible, then any person of any state or of any country who may wish to avail himself or herself of the opportunities offered by the school, and, finally, the industry whose best interests, we seek to promote not only by training men for the work, but by hastening the day when the basic truths, the underlying facts and laws governing ceramic operations shall be made known to all.

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THE RELATIVE THERMAL CONDUCTIVITES OF SILICA AND CLAY REFRACTORIES[1]

BY G. H. BROWN

The relative heat-conducting power of silica and clay refractories has given rise to frequent discussion. In gas retorts, by-product coke ovens and in all furnace installations where good heat-conductivity of the refractory materials is necessary to efficiency, the question is of great economic importance.

Reports[2] of wide variances as to the relative conductivities of the materials have been made, it being contended by some investigators that the silica or siliceous brick are less perfect conductors than the clay brick, although practical comparison appears to favor the silica brick as being the better conductors.

In comparing the heat-conducting powers of the various types of refractories, the wide variation in the physical structure and chemical compositions of the materials must be taken into consideration. In clay brick, we encounter structures ranging from coarsely ground and porous to finely ground and dense, and a chemical composition varying from that of kaolin to a silica content of from 65 percent to 75 percent. The degree of burning would also appear to be a factor in the heat conductivity of a refractory material.

We refer to a silica brick as being one manufactured from silica and sufficient lime to bind together the particles of silica. We have, however, silica brick composed of silica and a quantity of clay which acts as the binder; this variety is sometimes referred to as quartzite brick.

It is not unreasonable to expect a wide variation in the heat-conducting power among the many types of refractory brick upon the market.

A comparison of the thermal conductivities of silica, quartzite and clay bricks was recently made in the laboratory. As a suitable apparatus was not available for measuring the absolute

[1] By permission of the Director, Bureau of Standards.
[2] *Metallurgical and Chemical Engineering*, Vol. XII, No. 2, page 74.

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conductivities of the materials, we were restricted to a relative comparison. The test pieces were kindly furnished by the Laclede Christy Clay Products Co., of St. Louis, Mo., and were cylindrical in shape, five inches in diameter, and ten inches in length. A partial chemical analysis of the three refractories was as follows:

	SILICA	QUARTZITE	CLAY
	percent	*percent*	*percent*
SiO_2	95.48	83.36	63.24
Al_2O_3	1.92	11.79	32.97
Fe_2O_3	1.42	1.69	1.33

The three bodies were dense and apparently hard burned, the silica cylinder having a lime bond and the quartzite cylinder a clay bond.

The test pieces were placed horizontally in the wicket of a test kiln in a manner to leave one inch of the length of the material exposed to the furnace gases and one inch of the length exposed to the atmosphere outside the kiln. The eight inch portions of the cylinders passing through the wicket were insulated from each other and from surrounding material by a bedding of kieselguhr. Holes one and one-half inches in depth were drilled at right angles to the axes of the cylinders and one inch distant from the ends. Thermocouples were imbedded in the holes in the ends of the cylinders exposed to the kiln gases, the temperatures of the portions exposed to the outside atmosphere being measured by thermometers inserted in the corresponding holes. By this arrangement the temperature drop in the eight inches of material between the inside and outside of the kiln was recorded.

The temperature of the kiln was increased at the rate of 50° per hour to 1300°C. and simultaneous readings of the thermometers and thermocouples taken at intervals of ten minutes. The furnace was held at 1300°C. for six hours, equilibrium having been attained before that time.

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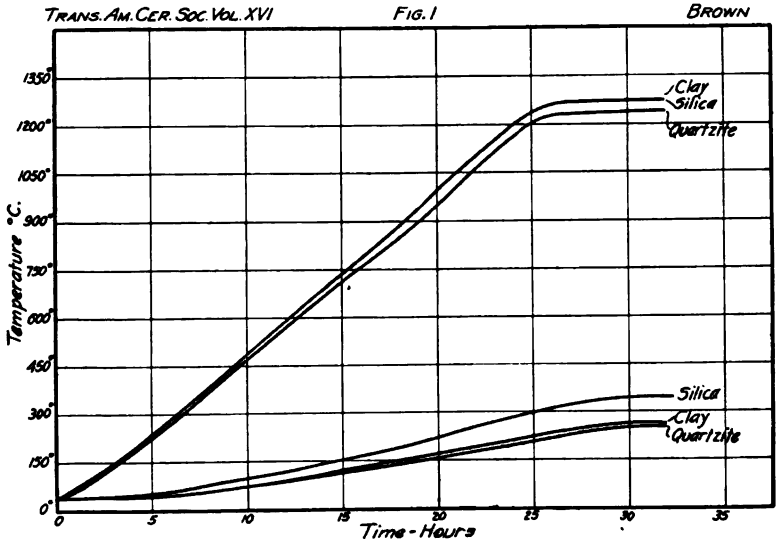
The upper curves in Fig. 1 indicate the temperature increase of the portions of the cylinders inside the kiln as measured by the thermocouples, and the lower curves indicate the increase in temperature of the portions of the cylinders outside the kiln as measured by the thermometers.

The differences in temperature, indicated by the readings taken inside the kiln, is probably due to the position of the test pieces in the wicket of the kiln, the clay and silica cylinders having been placed side by side and the quartzite cylinder near the top of the wicket in a position less exposed to the kiln gases.



After reaching equilibrium a temperature difference of 1017°C. is indicated between the two points eight inches apart in the silica cylinder, a difference of 986° between the two points eight inches apart in the quartzite cylinder, and a difference of 933°C. between the two corresponding points eight inches apart in the clay cylinder. The atmosphere temperature at the time the final readings were taken was 31°C. The relative thermal conductivities of the bodies, silica, quartzite, and clay, was therefore found to be in the proportion of 1017 : 986 : 933, the silica

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in this case having a thermal conductivity 8.99 percent greater than that of the clay, and the quartzite having a conductivity 5.68 percent greater than that of the clay.

DISCUSSION

Mr. Kinnison: In many engineering publications, questions have been answered recently regarding the relative conductivity of these two materials. The answers have been based upon the work done by the Frenchman, Wologdine, and always were to the effect that silica products were the poorer conductors. D. M. Marshall has brought out the fact that silica brick are burned at a higher temperature than clay brick, and that while the work of Wologdine applies to temperatures up to 1350°C., it does not apply to the temperatures at which silica brick are burned commercially (1600°C).

Prof. Orton: I privately asked Mr. Brown a minute ago, whether he had not done work on comparisons of these with other bricks; and he said that he had. The work is probably not far enough alone to use it in his reply now, but I wonder whether it cannot form a part of the paper itself. There are refractories on the market for use in making comparisons.

Mr. Brown: We have made comparisons of the conductivity of clay brick, silica brick and magnesite bricks at low temperatures.

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LABORATORY FURNACES

BY C. E. FULTON, CREIGHTON, PA.

The furnaces described will be found to be well adapted for use in laboratories where tests are made of refractory clays, or clay mixtures. These furnaces have been in regular use in the Research Laboratory of the Pittsburgh Plate Glass Company for the past two years and have given uniformly satisfactory results. By the use of these furnaces, we have been able to get very concordant results in check burns and great uniformity throughout all parts of the furnaces.

In our work we use two sizes of furnaces,—one which has a circular chamber 16 in. in diameter and 10 in. high while the other has a circular chamber 8 in. in diameter and 6 in. high. The larger one is used for burning trial bars and the smaller one for determining the deformation points of cones made from clays to be tested.

The larger furnace is made in three parts: the base, ring, and cover. (Fig. 1.) The parts are made by pressing or tamping into a wooden mold the fire clay mixture consisting of about 35 percent raw clay, 25 percent calcined flint clay, ground to pass a 6-mesh standard Tyler screen, and 40 percent of old fire bricks ground to pass a 3-mesh screen. The wooden mold (Fig. 3) consists of a ring and a core clamped to the bottom board as shown in the photograph. The fire clay batch is mixed thoroughly dry, and pugged several times to develop sufficient plasticity for molding. The consistency when used is a little softer than that required for making stiff mud bricks.

In forming the base and cover of the larger furnace, the core is not used. The fire clay mix is pressed or tamped into the mold until it is flush with the top—the ring of the mold being of the same height as the base of the furnace. The whole is then covered with a damp cloth and allowed to stand over night. The base of the furnace should then be firm enough to permit the removal of the mold and the cutting of the circular groove and the burner holes. The cover is made in the same manner and

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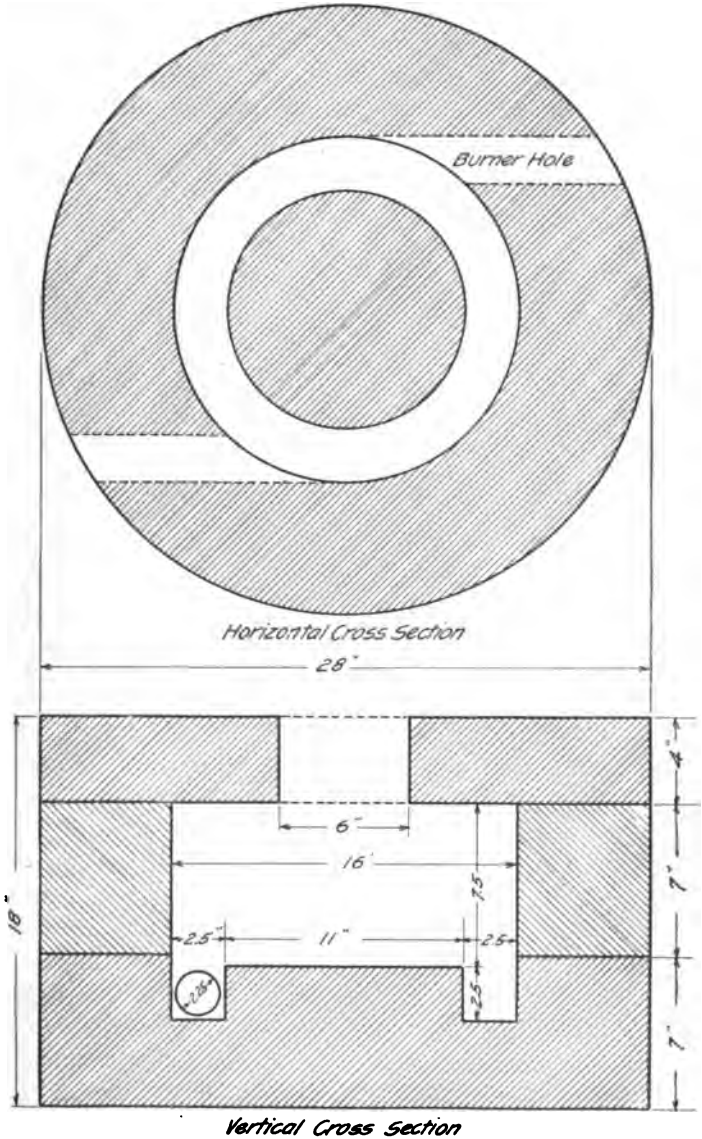
TRANS. AM. CER. SOC. VOL. XVI FIG. 1. FULTON



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can be made of any desired thickness by filling in the mold to any required depth. After the mass becomes firm enough, the mold is removed and the center hole cut.

To make the ring of the furnace, the outside of the core to the mold is covered with a damp cloth and fitted into place. The mix is then tamped in as before. After it has stood for two or three hours the core is removed, allowing the cloth to adhere to the clay.

FIG. 3

The parts of the furnace are dried slowly and burned to about cone 8. In setting up the furnace, a fire clay mortar is used between the base and the ring, and the exterior is coated with asbestos paste and then surrounded by a galvanized iron band which extends from the bottom of the furnace base to the top of the ring and through which two holes are suitably cut to permit the introduction of the burners. For convenience in handling, the cover may be cut in half before drying and burning. Figure 4 shows this furnace set up and in use.

The smaller furnace is built up by hand pressing,—using a

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TRANS. AM. CER. SOC. VOL. XVI FIG. 2. FULTON

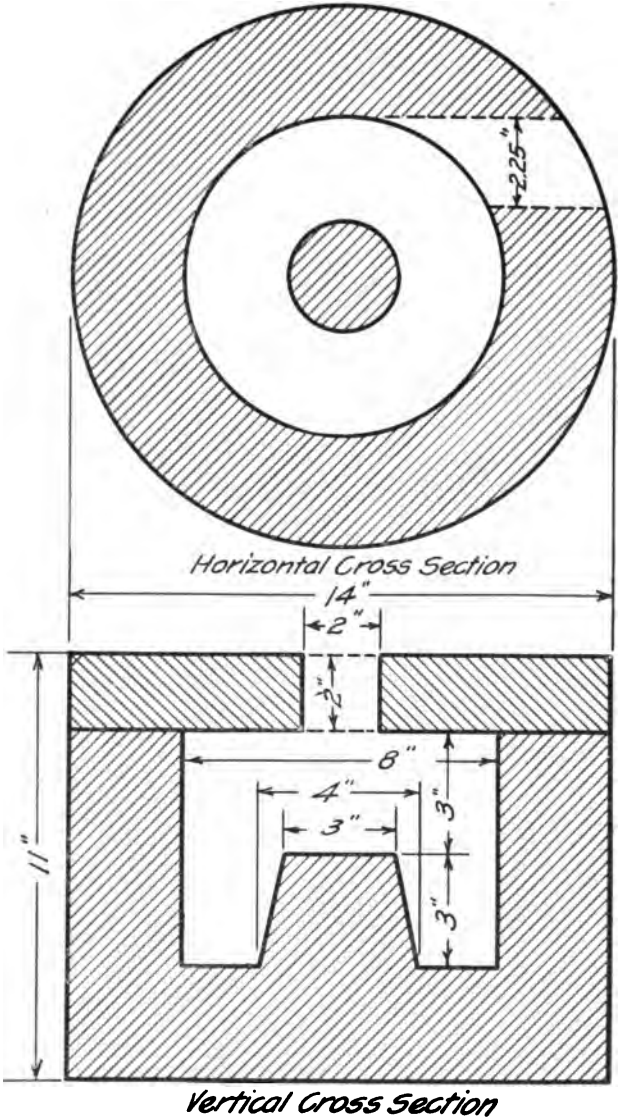

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FIG. 4

FIG. 5

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plaster mold to give it the outside shape. The same fire clay batch as given above is used to make this furnace. Figure 2 gives the dimensions, and Fig. 5 shows this furnace set up and in use.

These furnaces are fired with natural gas and compressed air, using the circular or spiral flame recommended by R. T. Stull and J. M. Knote.[1] The largest size injector burner made by the Buffalo Dental Manufacturing Company is used. The outside diameter of this burner is 2 in. and the length 12 in. Two of these burners are used with the larger furnace and one with the smaller. The burners project only about an inch into the burner holes, and when in operation the space around the burner is well mudded up. All gas and air connections are made with iron pipe, and the use of fire-inviting and otherwise unsatisfactory rubber tubing is avoided.

These furnaces will be found very simple and inexpensive in construction, and they can easily be made in any clay testing laboratory by a boy helper.

With gas at 2-2½ pounds and air at 40-60 pounds pressure, cone 20 (1530°C) can be attained readily in the larger furnace and cone 34 (1750°C) in the smaller. The temperature variation in either furnace is never greater than half a cone when proper care is taken to see that a correct mixture of gas and air is maintained.

[1] *Trans. Amer. Cer. Soc.*, Vol. XII, 124.

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THE FLOW OF CLAY UNDER PRESSURE[1]

BY A. V. BLEININGER AND D. W. ROSS, PITTSBURGH, PA.

The use of clay in the plastic state involves its function as a body possessing to some extent both the properties of a fluid and a solid. During the process of molding, it is caused to flow similarly to a viscous liquid, and upon being shaped, it is supposed to stand up under its own weight or greater loads without deformation. When subjected to a stress beyond that of its own weight any strain produced does not disappear upon the removal of the stress. It is therefore devoid of elasticity. The simplest assumption is that a plastic body should conform to the relation $W \div A = K$, where

W = the load imposed upon the specimen at any moment,
A = sectional area at that instant, and
K = a constant.

The stress-strain curve of a perfectly plastic substance should thus be a rectangular hyperbola corresponding to the relation: $Wl_1 = k$, where l_1 = length of specimen under compression at the instant the load W is applied. By taking a cylinder of plastic clay, subjecting it to increasing loads and noting the compression after each increment of weight the relation between the length of the specimen and the stress (or load) should result in a curve closely approaching a hyperbola. In this case the real stress is computed from the nominal stress from the evident relation:

$$S_1 = \frac{l_1 S}{l}$$

where S_1 = real stress = load divided by real area.
S = nominal stress, load divided by original area.
l = original length or height.
l_1 = compressed length.

By actually plotting load against length, curves are indeed obtained which in the case of plastic clays approach the hyper-

[1] By permission of the Director, Bureau of Standards.

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bolic form. The same relation referred to deformation would lead to the expression $d = k\ W$, where d = deformation. From this it appears that we are dealing here with conditions closely akin to the measurement of viscosity, and k in the last relation would be a constant expressing the viscous state of the clay-water system. Unfortunately, no agreement prevails among authorities in the field of mechanics concerning the term "plastic," and such eminent investigators as Unwin, Merriman, Martens, Goodman and others are divided in their views upon this subject. It is quite evident that the expression given above is only an approximation of the behavior of a plastic body, although use has been made of this principle in connection with the study of clay by Zschokke[2] and Grout,[3] the former applying it to tension, the latter to compression. To secure light upon the subject a great deal of experimental work remains to be done in order that the deformation of clay, in the plastic state with varying water contents, be studied from the standpoint of mechanics.

The greater the water content, the greater a departure we should expect from the plastic condition as the fluid state is approached. The present work aimed to determine the degree of fluidity of clay in the plastic state proper, with varying water content. A comparison is obtained by studying the flow of a perfect fluid like water.

Liquids are caused to flow under pressure in accordance with a definite law which is expressed by the formula:

$$V = \sqrt{2\,gh},$$

where V is the velocity in feet per second and h the head in feet above the discharge orifice, g being the gravity constant, 32.2 foot pounds. The actual discharge of a fluid under any given pressure depends also upon the viscosity of the fluid and the character of the orifice. In the case of water and a plain round orifice with sharp edges the flow constant becomes approximately 0.62, so that the actual discharge is represented by the relation:

$$Qu = 0.62\ A\sqrt{2\,gh},$$

where Qu is the quantity discharged and A the sectional area.

[2] *Baumaterialienkunde*, (1902) Nos. 24, 25, 26 and (1903) Nos. 1-6.
[3] The Plasticity of Clays, *Jour. Am. Chem. Soc.*, 17, 1037-49.

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An orifice which is rounded so as to form a contracted jet increases the friction somewhat, but the discharge coefficient is increased much more so that it approximates 0.95. For different orifices varying velocity coefficients will result. Although the discharge coefficient may vary, the function $v=K\sqrt{2gh}$. remains parabolic, since $v \propto \sqrt{h}$ excepting for great pressures. For high pressures the compressibility of water must be taken into account, which corresponds to a modulus of elasticity of 310,000 pounds per square inch. Thus the density is increased one per-cent under a pressure of 3000 pounds per square inch.

The parabolic formula thus offers a criterion of the fluidity of clay. If the latter were a liquid though possessing a relatively high viscosity, the velocity-pressure relation would still remain parabolic in spite of a low discharge coefficient due to the viscous condition. If, on the other hand, the increase in viscosity becomes very great, the condition of a plastic body is reached in which the internal friction is so enormous that the fluid character of the mass tends to disappear. For low water contents, the condition of a rigid body would be finally approached.

In the present work the relation between pressure and the flow of clay was studied by forcing the latter from a brass cylinder through an orifice. The cylinder first used was 1.75 inch in diameter, inside, 3.5 inches in length and closed at one end by a plate 0.25 inch thick provided in the center with a hole 0.25 in. in diameter through which the clay was expelled. The edges of the opening were sharp. A tight fitting piston was made to work in the cylinder. Later, a heavier cylinder of 2 inches inside diameter and 4.75 inches length was used, with the same orifice, 0.25 inch. The piston head was 2 inches long to provide proper guidance and also possessed a heavy bearing plate at the outside end. The cylinder, filled with clay, with the piston head inserted its full depth, was placed between the top and bottom plate of a 10,000 pound Olsen testing machine, the orifice being on top. An aperture of ample size in the upper head of the machine permitted the escape of clay. The testing machine was sensitive to

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two pounds and was operated by hand. Figure 1 illustrates the testing arrangement. Two kinds of data were obtained, first the pressures required to start the flow of the clays with different water contents; secondly, the quantities of clay discharged through the orifice per minute, with varying pressure and again with different contents of water.

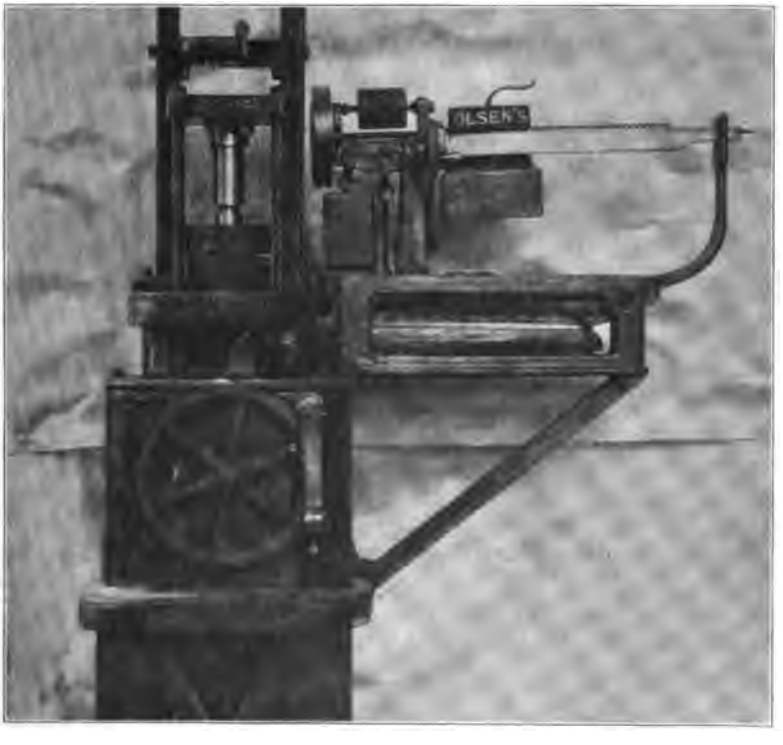

FIG. 1

Pressure Required to Start Flow. The operation as carried out was as follows: The cylinder was filled with clay and placed in position in the machine. The pressure was then applied very slowly until flow began to take place. A sample of the clay was taken and dried at 110°C. for the determination of the moisture content.

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Sixteen clays were examined in this manner with moisture contents varying from the condition in which the mass was exceedingly stiff to that in which it had become very soft. The results of these tests applied to eight characteristic clays are shown in Fig. 2. The different types of clay naturally arrange themselves in the order of their water content. High pressures are required to cause flow of the clays when they are deficient in water i. e., when very stiff, and it is seen that in this state they rapidly approach the condition of a rigid body, since this part of the curve tends to become a line parallel to the abscissa. As more water is added the curve rises gradually away from the x axis, and at the same time the pressure drops at a decided rate. When the most plastic state is reached as determined by the feel a pronounced curvature occurs. This point (indicated by crosses on the curves) therefore is very close to the turning point of the curve where it approaches the y axis and later rises with a steep gradient and with a distinct tendency to become parallel to the ordinate. From here on the mass inclines toward the liquid state. Theoretically, the point of optimum plasticity should correspond to the intersection of the solid-liquid pressure curves, and indeed this is shown to apply. The curves themselves are hyperbolic in charcter, as is to be expected.

Owing to the wider range of the water content of the ball clay and plastic kaolins, the radius of curvature of their curves is, of course, greater than in the case of the clays, the consistency of which is dependent on a more limited percentage of water. The transition to the fluid branch of the curve must be, therefore, more abrupt in the case of the latter than for the former. The pressures required to cause flow of the clays in their most plastic state do not differ very greatly, and vary between 33 and 84 pounds per square inch. Owing to the fact that we are dealing here only with the initial pressures required to start flow, the velocity is practically nil, and hence the values represent the minimum under practically static conditions. The enormous increase in pressure with drop in water content illustrates very well the extreme fluctuations in power requirement to which auger machines and sewer pipe presses are subject.

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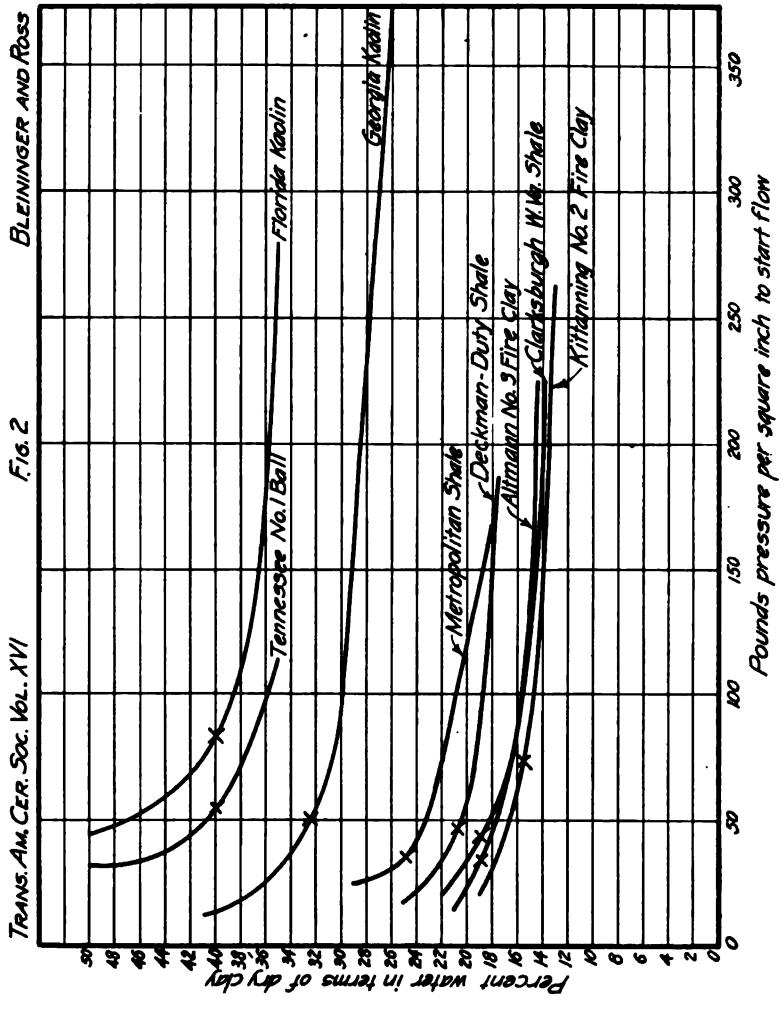

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Rate of Flow Under Different Pressures. These tests were made by again filling the cylinder and causing the clay to flow under constant pressure, a condition which was maintained by keeping the beam of the testing machine in the floating position, the rate of applying the load being thus regulated. After the flow of clay was well started at the pressure selected the quantity expressed per minute was obtained by weighing. The water content was determined as usual.

Two sources of error were encountered which it was impossible to overcome. One of them was the squeezing out of water from the clay, especially at the higher pressures which left the remaining clay in a stiffer condition. The other was the inability of the operator to turn the crank with sufficient rapidity to maintain the constant pressure when the rate of efflux was quite high. This difficulty could have been overcome by the use of a variable speed motor suitably connected up, which, however, was not available. This error applies only to the soft mixtures.

The results are presented in the diagram of Fig. 3, in which the middle curve of each set of five is that of the best plasticity. The curves as a whole are entirely unlike the parabolic curve representing the flow of a liquid under varying pressure. The former are more or less convex, the latter is concave. It is evident, therefore, that the law of liquid flow does not hold in this case. With low water content, the pressure required to bring about definite flow per unit time rises very rapidly. As the water content becomes higher, the rate of pressure increase becomes smaller and the curve flatter. Finally, with very soft consistencies, small increments of pressure suffice to cause a large increase in the amount of flow, as is to be expected under the conditions of the experiment. As soon as the initial resistance is overcome, the soft clay flows very easily, and it is reasonable to expect that it would obey the law of flow of liquids with larger quantities of discharge which we were unable to determine. This is indicated also by the fact, that the direction of the curvature changes with an increasing water content and would undoubtedly approach the locus of the parabola.

The pressure required to bring about a definite discharge per

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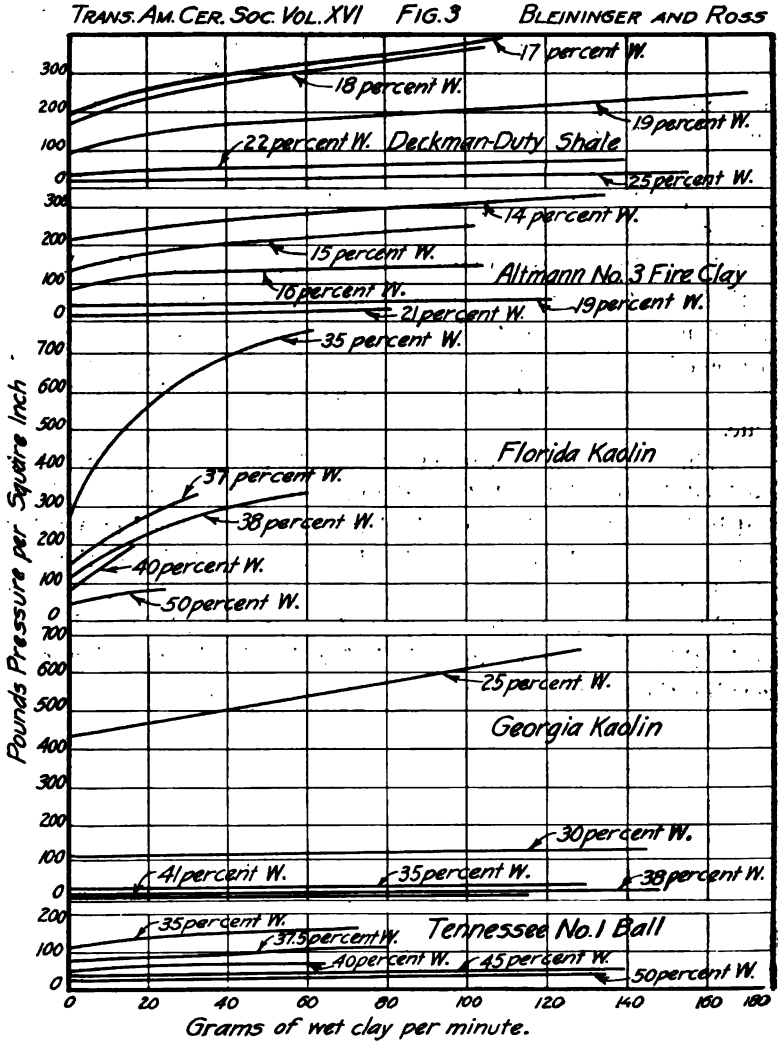

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minute for an average plastic consistency varies also with the character of the clay. It seems to be highest for the Florida kaolin and followed in descending order by the shale, plastic fire clay, Georgia kaolin and Tennessee ball clay. The most plastic clay, therefore, the ball clay, requires the least pressure to produce unit flow. The data is not sufficiently extensive to allow of any generalization with reference to the characteristics of the clays in this respect.

The behavior of clay in regard to flow under pressure was thus found to vary according to the inherent nature of the material and its water content. Its properties constantly change with fluctuations in the proportion between clay and water. With a low moisture content, the properties of a solid body are approached and with much water those of a fluid. The statement frequently made that plastic clay behaves like a liquid is not true.

The present work cannot be said to have brought out any decided differentiation betwen the more and the less plastic clays, but it does not seem improbable that with more refined apparatus some pertinent data may be developed. The study of the mechanical properties of plastic clay, although difficult of approach should receive more attention from the experimental standpoint, as in this direction we must look for definite information concerning the nature of clay.

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ADDITIONAL NOTES ON THE POWER CONSUMPTION OF STIFF-MUD BRICK MACHINERY

BY RICHARD R. HICE

In Volume XIV of the *Transactions of the American Ceramic Society* I had a short note in reference to the actual power consumption of a stiff-mud brick plant. At that time the plant in question, having just been rebuilt, was not running to its capacity, nor was the entire equipment, as planned, in operation. The power consumption was at that time figured at 30.4 kilowatt-hours per M. brick.

Since these figures were given, a crusher plant has been added, operated by one 25 H.P., 60 cycle, 2-phase, 250 V., squirrel-cage type motor, and one 5 H.P. motor to operate the conveyor to the storage bin. There has been a reduction of ten percent in the size of the brick manufactured. Aside from these changes the equipment and product remain the same.

It is evident that the change in the size of the brick made, requires no difference in the power consumption per ton of product for grinding, elevating or pugging. There is, however, some slight increase in power required by the brick machine. How much additional power this may require is unknown, but I have assumed it would require an additional five percent.

While the crusher plant is equipped with two motors, of 30 H.P. capacity, these are carrying their full load but a small portion of the time, and the additional power required is small compared with that of the motors installed.

For the purpose of comparison with the former figures of power consumption, I have taken the output for the last six months of 1913. During the period 4,593,000 brick were made, with a total power consumption of 136,380 kilowatt-hours, an average of 29.7 kilowatt-hours per M. brick made. If we assume that owing to the smaller size of the brick made the power consumption per M. brick was 95 percent of what it was with the brick formerly made, this would represent a power consumption of 31.3 kilowatt-hours per M. brick of the former size, practically

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1 kilowatt-hour above the former experience. This would probably quite closely represent the additional power required in using the crusher plant.

In comparing the power consumed during this period month by month, we find the power used per M. brick to be:

July	29.58 kilowatt-hours
August	30.55 kilowatt-hours
September	28.35 kilowatt-hours
October	28.76 kilowatt-hours
November	31.11 kilowatt-hours
December	30.08 kilowatt-hours

The variation in the current consumed seems to bear no relation to the number of brick made, as may be noted in the annexed curve. There does not seem to be any relation between other conditions, which might affect the working to some extent, and the power used. It is true the consumption in September and October was the lowest in the six months, but no reason is apparent why the consumption in August should not have been as low as that of September or July. The peak in November might be explained by the bad weather conditions which existed in that month, but the relation seems remote.

On the whole it seems that the actual results of the six months under study compare very closely with the former experience, and it would be safe to say that a brick of the character made, 8⅝ in. by 4¼ in. by 2⅜ in. in size, with the machinery equipment of this plant, will consume about 31.5 kilowatt-hours per M. brick, which for a brick 8¼ in. by 4 in. by 2⅜ in. would be reduced to approximately 30 kilowatt-hours.

It is almost impossible to compare the results from different plants, especially to compare data furnished by other parties, for the reason that generally due allowance is not made for the character of machinery equipment, the power required for elevators, for pumping water, operating drills and other purposes, the material used or the character of the product made. Neither can it be overlooked, that where the plant is not operating to its full

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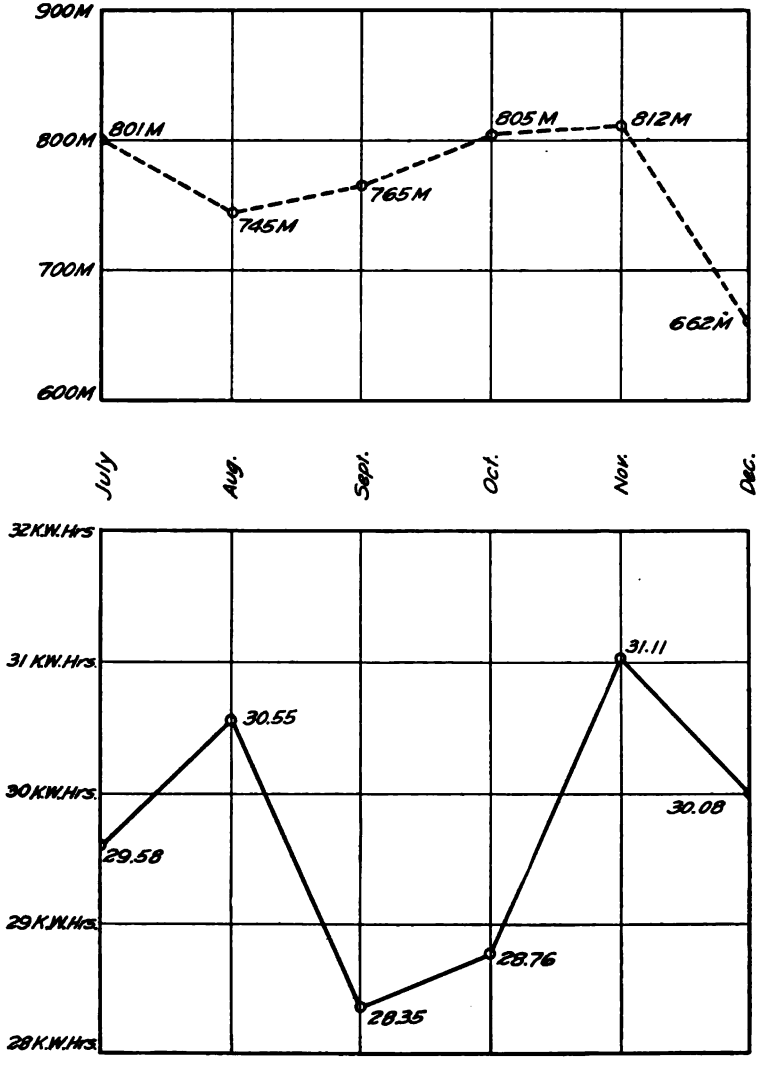
TRANS. AM. CER. SOC. VOL. XVI FIG. 1 HICE



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capacity, the power consumption per unit of product will be quite largely increased.

Data is at hand of one plant equipped with a 9 foot dry pan and elevator, pug mill, brick machine and represses, with a total installed power of 157 H.P. It is probable that the one dry pan in this case limits the output, which is said to be approximately 10,000 fire brick per day. The power consumption of this plant is approximately 45 kilowatt-hours per M. brick, which would be equivalent to probably 37 kilowatt-hours for a brick 8¼ in. by 4 in. by 2⅜ in. On the other hand, the output of this plant is rated as fire brick, and it is altogether probable that the clay is used much coarser for that reason, which would reduce the power required for grinding. No information is at hand regarding the character of the clay.

At another plant equipped with two 9 foot dry pans, one combination pug mill and auger brick machine, one combination pug mill and press-type brick machine, automatic cutter, elevators, and crusher, with a total installation of 130 H.P. in motors, the apparent consumption of power is 23 kilowatt-hours per M. brick. However, this plant is manufacturing fire brick and oven-bottom tile, and some material is molded by hand. Probably the most of the product is made on the press-type brick machine, which requires less power than the auger style of machine.

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WEATHERING OF FIRE CLAYS IN THE MANUFACTURE OF FACE BRICK AND PAVING BLOCK

BY L. B. RAINEY, NEW BRIGHTON, PA.

When visiting the various shops in eastern Ohio and western Pennsylvania one cannot help but notice the large percentage of the labor cost of operation used in feeding the dry pans. In a factory of large capacity from three to five men are used in wheeling the clay to each pan. The idea prevails that good material cannot be made, unless the clay receives a few weeks of weathering or airing after coming from the mines.

Expensive crusher outfits will be installed at the top of the incline or shaft where the clay is brought from the mine, and the clay will be crushed and taken to stock piles by chutes instead of being fed to the pans direct, which would save the labor of about six men on a battery of two pans. From these stock piles, it is usually wheeled to the pans at a large cost.

It was the opinion of the writer that this was all wrong and unnecessary. After visiting several factories, studying their methods of manufacture, drying and burning, and the results as shown by the finished products, this opinion seemed verified.

At one of the larger paving block factories of eastern Ohio, the common practice was to air the clay for about two to four weeks. For about two months, the use of the clay just as it came from the mines was tried out. The analysis of the clay is as follows:

SiO_2	58.10
Al_2O_3	29.60
Fe_2O_3	1.20
CaO	0.40
MgO	0.54
K_2O	1.75
Combined H_2O	8.75
	100.34

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The green clay seemed to work as well as the aired clay with these few differences: The green clay was much more abrasive and wore out the machinery parts faster, such parts as screen plates in the pans, pug mill knives, augers, propellers, machine dies and repress dies. The shrinkage was practically the same, with both clays, and runs about six to eight percent.

The drying system used hot air, heated by being drawn through steam coils, the steam coming from the exhaust of the Corliss engine. The tunnels were 80 ft. long, and the temperature about 125° at the cold end and 165° at the hot end. The block averaged about 36 hours in the tunnels and when drawn were fairly dry, and in good shape for setting.

Difficulty was experienced at this stage, however, by the appearance of small cracks in the block. This trouble was largely overcome by the use of one-fourth pound of salt to each wheelbarrow full of clay as it was fed to the pans. Practically no difference could be noticed in the burning of the material, and as near as could be judged the heat treatment was the same in both cases, the same cones were used, and the same settle recorded as before. The similarity of the burning actions can be explained by the fact that no important difference is brought about by the small amount of weathering it gets which is of too short duration to bring about mineralogical changes. The weathering of iron sulphide, lime, and alkali salts requires a longer time than that given to the weathering of the clay. The clay is dropped into stock piles on the ground, and very little drainage takes place, hence the rain, snow and frost would accomplish but very little in this limited time.

When the kilns were drawn, the percentage of first and second quality brick ran about the same in both aired and green clay. In making rattler tests of the material it was noticed that the results fell off from one to two percent, that is, a block made of aired clay would stand a test of 18 percent while a block from green clay would run from 19 to 20 percent. At this factory, however, this was no draw back, since the material was still of high enough quality to pass the city inspection tests, and no trouble was experienced.

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Another point noted from the condition of the block and the results in the rattler test, was that kilns made from green clays, to give good results, seemed to require more cautious cooling after the firing was finished. It was found to be good practice to add about one day to the cooling period, making it six days from the finish to the time of drawing instead of five, as before. The doors were torn down, and the crown holes opened to correspond to this increased period.

When cooled too quickly, the blocks had no life and went to pieces in the rattler; they also showed a tendency to check in small spider-web size cracks. This applies particularly to block in the doorway of the kiln.

Results were noticed in a factory in western Pennsylvania manufacturing a face brick of the flashed type, using the No. 2 fire clay of the Lower Kittanning vein. The analysis is as follows:

H_2O	5.97
SiO_2	69.34
Al_2O_3	24.22
Fe_2O_3	0.08
MgO	Trace
Lime	None

This clay is fed direct from mine to pans. The results seemed identical with those noted before, except that no trouble was experienced in the drying tunnels at this factory. The dryers are of the radiation type, direct fired, and burn coal for fuel.

The brick came out bone dry and entirely free from cracks.

The burning is done in down draft, periodic kilns, and the methods used were the same in both cases. The brick from green clays when drawn, however, are of a decidedly brighter color than the brick from aired clay. The kilns required more time and labor in sorting due to the fact that the clay comes from different parts of the mine, a car coming from one room on one side of the entry and the next car coming from a point in the mine possibly 100 yards distant, the clay not running uniform over the entire mine. This can be controlled by running the clay into

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a large bin where it would mix, and then feeding by chutes to the pans direct.

The different shades, however, were all desirable shades, and the small amount of extra time required in sorting did not amount to anything in view of the large saving made by using the green clay and by only handling it once.

In conclusion, I think that by the expenditure of a few hundred dollars and the use of green clays in the proper manner, that nine factories out of ten in the district mentioned (this applies to face brick, paving block and sewer pipe factories) could eliminate five to seven men at the dry pans, or such expensive apparatus as clam shell shovels, steam shovels and other mechanical devices.

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A LABORATORY OVEN PROVIDED WITH RECORDING ATTACHMENTS FOR THE STUDY OF THE DRYING OF CLAYS[1]

BY A. V. BLEININGER, PITTSBURGH, PA.

In comparing clays with reference to their behavior in drying, it is essential first of all that the conditions be kept as constant as possible. It is necessary that the initial volume and shape of the specimen be kept the same, and that the temperature, humidity and velocity of the air used in drying be kept constant. Unless such conditions prevail, it will be impossible to arrive at definite data concerning the rate of evaporation of water from the clay, since there are too many variables involved to make possible a solution. Under ideal conditions, the only variable remaining should be that expressing the physical structure of the clay in its effect upon the rate of drying. In order to establish such conditions the drying oven described in this paper was constructed. It might be stated in advance that such refined control as is practiced in physical-chemical work, where, for instance, the temperature is controlled to within one-hundredth of a degree, was not considered necessary, considering the large size of the specimen and the desired degree of accuracy.

In brief, the apparatus consists of a pressure regulator, controlling the flow of air into the dryer, a desiccator for producing practically a constant, minimum humidity, a heater provided with a thermostat for raising the air to a constant temperature, and the drying oven proper, in which the loss in weight and the shrinkage are being recorded automatically.

The air used is obtained from a compressed air line, and the flow is regulated by means of a pipe immersed to a definite depth in oil, which is contained in a two inch pipe. The line valve is so adjusted, that a slight excess of air is always provided which constantly bubbles up through the oil. With a higher initial pressure the volume of air thus escaping is greater, and less

[1] By permission of the Director, Bureau of Standards.

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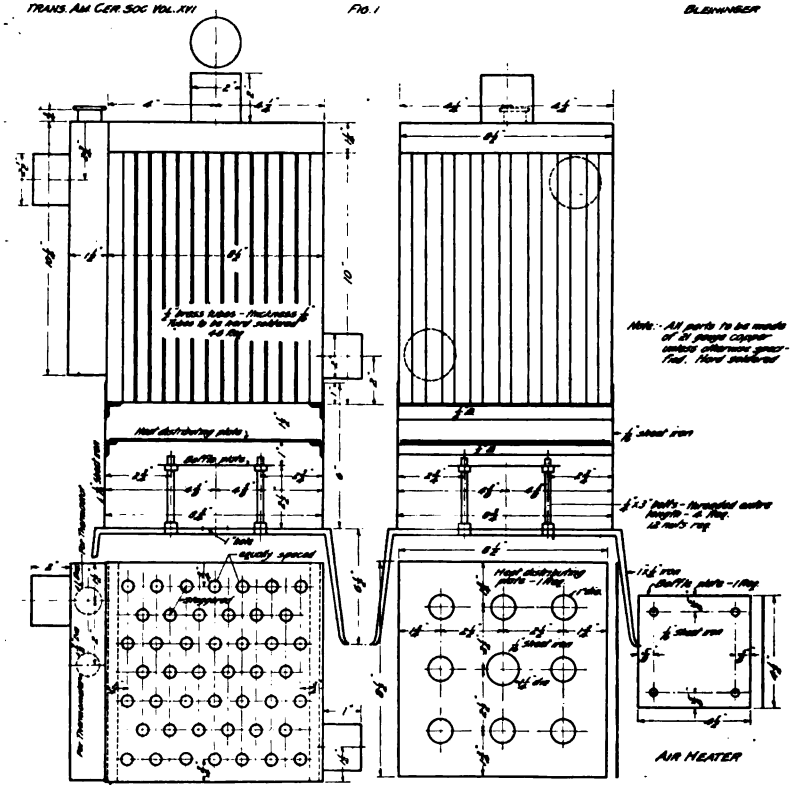
with a decrease in pressure. A large bottle inserted between the line and the pressure regulator removes any water carried along by the air. A pressure gauge, graduated to hundredths of an inch of water head, is provided between the regulator and the dryer, and serves to control the pressure under which the air enters the dryer. It is kept constant at 0.14 of an inch.



The desiccating chamber consists of a galvanized iron box, painted on the inside with asphaltum paint, and is 18 in. high, with a cross section of 12 in. by 10 in. It contains nine screen pans, composed of a frame covered with 20 mesh screen cloth, which are placed in position, horizontally, in such a manner that the current of air which enters at the bottom is compelled to flow

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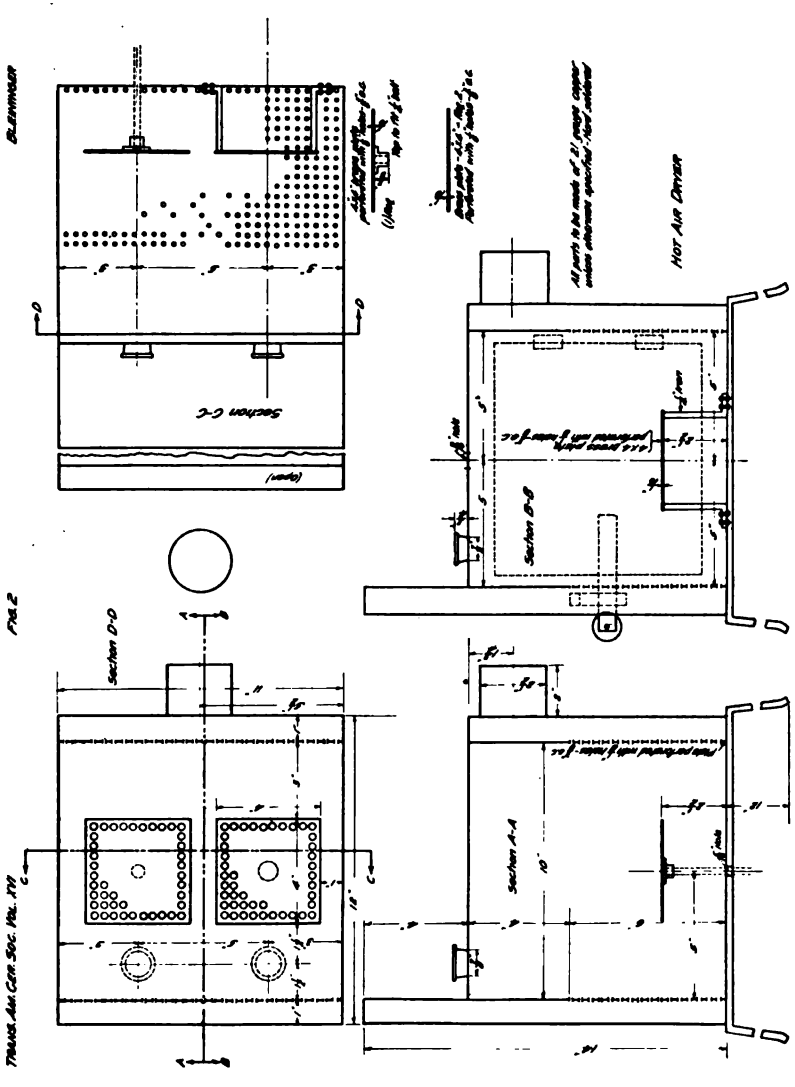

FIG. 2

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through the chamber zig-zag fashion over the entire surface of the pans. The latter have sides one-half inch high and can hold about six pounds of calcium chloride. The desiccated air leaves through a 2 in. pipe at the side and near the top of the desiccator. The volume of this receptacle and of the pipes is so large that the velocity of the air is small, and friction losses very slight. The air then flows through a goose neck to the heater, where it enters at the bottom into the distributing space, of the cross section of the oven and 1½ in. high. The heater has a height of 13¾ in. over all and a cross section of 8½ in. by 12 in. The air flows upward around 46 vertical brass tubes, one-half inch in diameter and one-sixteenth inch in thickness, arranged in staggered rows. These are heated from the inside by the hot gases from a gas burner below the oven. The heat of the flame is distributed by means of a baffle and a perforated plate. The combustion gases escape on top from a space communicating with the brass tubes. The heated air is drawn off to a collecting space through a 2½ in. opening and into a 2½ in. pipe conveying it to the dryer proper. Tubulatures are provided on top for the insertion of a thermometer and the brass cylinder of the thermostat. The latter is the Bean regulator, electrically operated and regulates the gas supply to the burner by opening or closing a ball valve. A pressure regulator of the floating tank type also controls the pressure of the gas. The oven is covered with asbestos lagging. The drying oven is also made of copper, heavily lagged, and consists of a chamber 11 in. by 10 in. by 10 in., connecting on one end to a distributing space one inch wide and on the other with an exit flue of the same width and 14 in. high. The heated air upon arriving in the distributing space is compelled to flow through a perforated partition, having numerous openings of ⅛ in. diameter, ⅜ in. center to center. In this manner any currents are broken up and the flow rendered more uniform. Similarly, on the opposite side, the partition wall is of the same character arranged for the same purpose in regard to the exit of the air.

Two clay specimens are required, 2 inches high and 3.14 inches in diameter, made from the same lump of clay. One of

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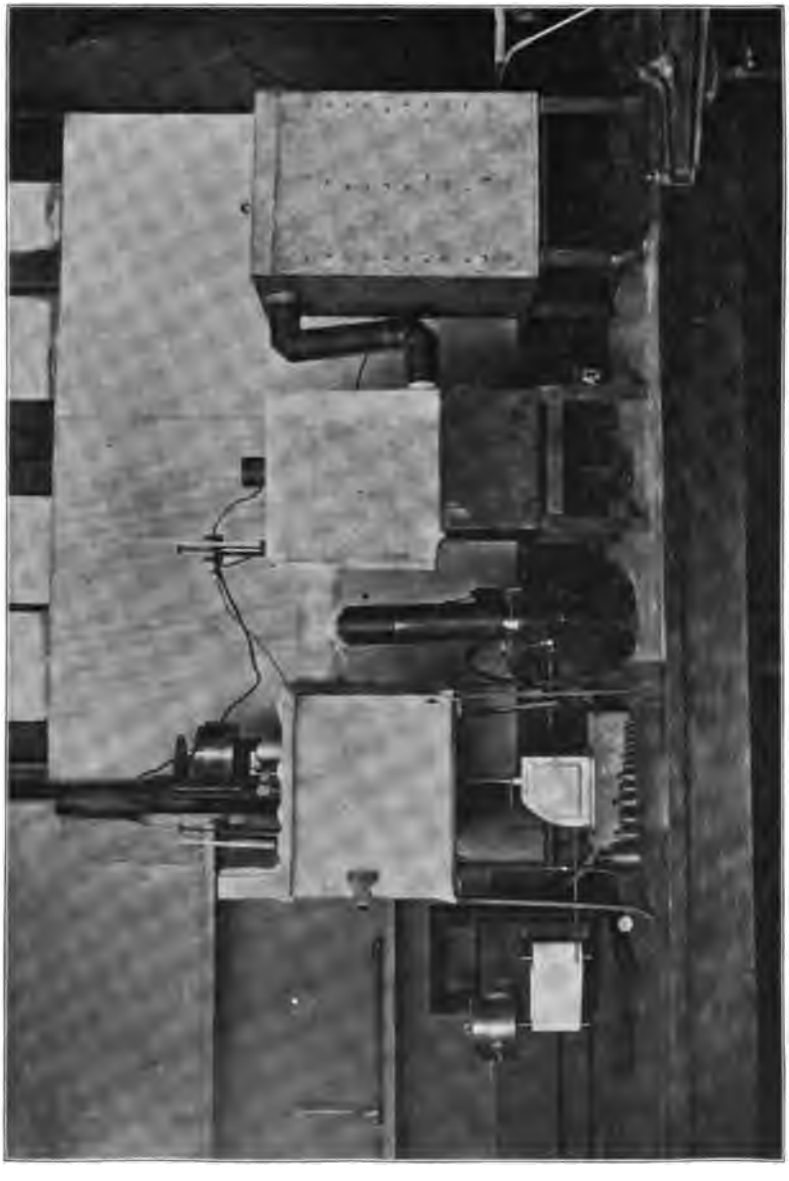

Fig. 3

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these is placed on a perforated brass plate attached by means of a rod to a postal scale underneath the oven. The scale was carefully calibrated before using it. A long thin bar attached to the pointer of the scale and provided at its extremity with a pan, records the weight upon a chart running on two brass rollers, 3¼ in. long, with diameters of 2 in. and ¾ in. respectively. Owing to the length of the pointer the reading is considerably magnified. The clay cylinder is covered on top with a brass plate similar to the bottom one. The other clay specimen is supported by a perforated brass plate fixed firmly in position and is likewise covered with a perforated top plate. A brass rod rests upon the latter and extends out through the oven, forming the fulcrum of a long brass lever to which a pen is attached near the end. A greatly magnified record is made upon a clock driven chart. The dryer is also provided with tubulatures for the insertion of thermometers. The apparatus thus records the shrinkage and loss in weight of the two cylinders simultaneously. The specimens are introduced through a large door in the front side which is provided with grooves so as to form tight joints. Although, of course, the usual adjustments have been found necessary and improvements could undoubtedly be made, the apparatus works very satisfactorily. At first a considerably more elaborate construction was contemplated, but the lack of funds made necessary the use of the present form.

The diagrams of Figures 1 and 2 show the construction of the heater and the drying oven proper and Fig. 3 the appearance of the complete set-up.

In operating the dryer, a lump of clay in the plastic state is prepared by thorough wedging from which two cylindrical pieces 2 in. high and 3.14 in. in diameter are pressed in a metal mold. These specimens weigh about 540 grams each. They are put in a tightly closed vessel containing some water, for 24 hours, when they are weighed and placed in the dryer which has been brought to the standard temperature, 62°C.

Some of the drying curves during the earlier part of the work, while some adjustments were still being made, are shown in the diagram of Fig. 4. These curves may be used to represent

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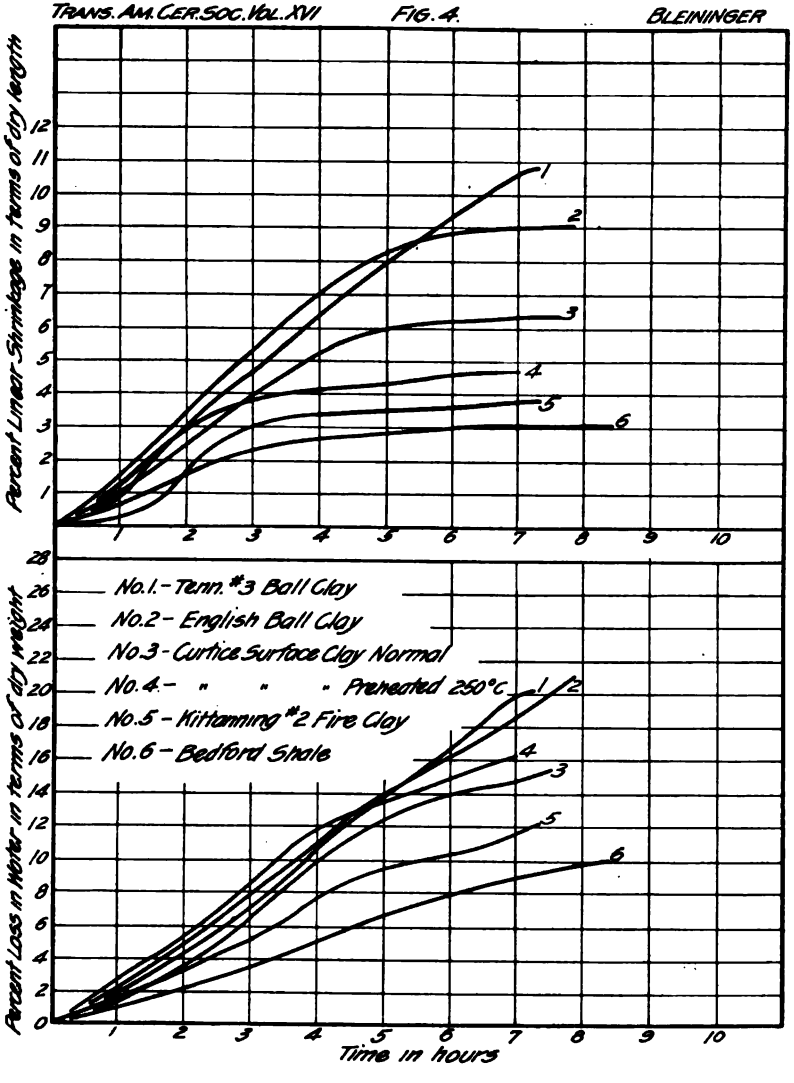

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the drying behavior of the clays, and from them a value is obtained which expresses their characteristic quality with respect to drying. Such a factor would be the mean value of the drying shrinkage covered by the time, between the origin of the curve and that point at which shrinkage has ceased. Thus, if shrinkage is represented by y, and time by x, and the beginning and end of the time interval by o and t respectively, the mean value of y between x=o and x=t is obtained by the expression:

$$\int_{o}^{t} \frac{y\ dx}{t}$$

The integration may be accomplished by determining the area enclosed between the curve and the points o and t on the x axis, using either the planimeter, computation of the mean ordinate or Simpson's rule. This value is then divided by t and the mean value of y thus obtained. This expression gives the average percent of shrinkage, in relation to the time of drying. The greater the value, the more difficultly does the clay dry. It is, of course, important in this work to fix the point at which shrinkage has ceased, as accurately as possible, which is not difficult. The mean shrinkages shown by the six clays represented in the diagram of Fig. 4 obtained by means of this planimeter are as follows:

Clay No. 1	5.60 percent
Clay No. 2	5.80 percent
Clay No. 3	4.25 percent
Clay No. 4	3.30 percent
Clay No. 5	2.46 percent
Clay No. 6	2.05 percent

It is also possible to calculate a factor involving the loss of water as well. As far as this work is concerned, only the water which is evaporated during the shrinkage period is of interest. Thus the mean loss of water (by weight) up to the point at which shrinkage has ceased might give a factor characteristic of the clay. The curve likewise is capable of bringing out certain accelerations and retardations which may be of significance.

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as, for instance, in curve No. 5. The work has not progressed far enough to go in sufficient detail into several points which have been brought out.

DISCUSSION

Mr. R. J. Montgomery: I want to speak of one point in connection with this paper. Mr. Bleininger spoke of using a sample two pounds in weight. That would be a fairly good size block. I wonder whether in comparing the shrinkage and loss of water, he took into consideration the surface drying. Any ordinary rate of evaporation would give surface drying, and the shrinkage would not be proportional to the water present.

Mr. Bleininger: Evaporation is bound to take place from the surface, and not until shrinkage has ceased will inter-poral evaporation come into play. There must be flow from the interior towards the surface, and I do not see how this will affect the test.

Mr. R. J. Montgomery: I mean that the water is not uniformly distributed throughout the piece. The drying comes on the surface first, and there is higher moisture toward the center of the piece. The water then is not proportional to the shrinkage, because you have not a uniform water-content throughout the piece.

Mr. Bleininger: The shrinkage is coincident with loss in weight, and the two are proportional. Of course the point that you bring out applies equally to all drying clays. The main thing, however, is to get consistency in operation. The minute you produce variations of any kind or complicate the drying, you cannot compare the drying figures of one clay with those of another.

Mr. Montgomery: In this method would you not have to use the same sized test pieces for all clays?

Mr. Bleininger: Yes.

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POTTERS' ROTARY STOVEROOMS

BY HERFORD HOPE, BEAVER FALLS, PA., AND B. D. HARDESTY, CANONSBURG, PA.

As is well known to the majority of potters, rotary stoverooms have been used for many years in Europe, but so far as the writers are aware, their use in the United States has been very much restricted.

Their chief advantage over the prevailing type of stoverooms, lies in the greatly lessened distance the moldrunner has to travel, thus considerably lightening his work. Owing chiefly, no doubt, to the fact that a scarcity of boy labor has been acutely felt only within the last few years, very little thought has been given to making the work easier; but during the summer of 1913, the jiggermen of the East Liverpool potteries, in particular, were handicapped to such an extent by the lack of necessary boys, that many jiggers were idle, and the output of the potteries perceptibly reduced. Not only does the use of rotary stoverooms lessen the work required of the moldrunner, but working conditions are improved by almost entirely preventing the continual running into and out of a heated and moist atmosphere. A jigger supplied with these stoverooms is shown in Fig. 1.

With a shorter mold running distance, and consequently more time to spare, the moldrunner can always keep the batter-out supplied with molds, and thus the occasional delay in filling molds is prevented, and the jiggerman's output increased. Where two moldrunners are necessary under the prevailing system of stoverooms, one is sufficient when using the rotary type. In short the advantages to the jiggerman are sufficiently evident and render unnecessary further discussion on this point.

In this case, as in others in which the workmen are directly benefitted, the argument is often advanced that no advantage accrues to the firm in return for the cost of replacement of the stationary stoverooms by the rotary type (though in new construction there is not much additional cost in building the lat-

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FIG. 1

FIG. 2

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ter). At first sight this appears to be true, but a brief consideration of the matter will lead to the following conclusions:

1. Where the best working facilities are provided it is easier to secure the best workmen, other things being equal.

2. Although no reduction in the current piece-work prices paid for jiggering are anticipated in adopting an improvement such as that under discussion, yet as the cost and difficulty, in securing help, increases, it would be necessary for the jiggermen to secure an advance in price, so that their net wages would not be decreased. The rotary stoverooms, by saving labor, thus tends to prevent increase of manufacturing cost.

3. The increased output, due to more regular attendance of the boys, provides for the more prompt filling of orders and tends to reduce the proportion of dead expenses.

Before proceeding to a detailed description of the construction of the rotary stoverooms, a brief account should be given of the other types, the ordinary or fixed, and the drawer or slide stoveroom.

A description of the first is hardly necessary, so universal is their use. It will suffice to state, that they are usually 14, 16, or 20 feet long, about 8 feet high, and 4 feet or 4 feet 6 inches wide, the shelves being usually 8, 10, or 12 inches wide, and running the entire length. The steam pipes are placed the length of the floor, preferably under the shelves, sometimes in the middle of the room, and then they are covered with a false floor.

The drawer or slide type, which has much to commend its use, consists of shelves 7 or 8 feet long, fastened between two heavy boards which form the ends of each slide and which are suspended from the axle of a sheave running on an overhead track, (preferably of iron so that no warping can take place). The two ends are tied together with rods running parallel to the shelves. As each drawer or slide is pulled out for use, the rear end board closes the space from which the slide has been drawn. This arrangement will be clear by reference to Fig. 2, from a photograph taken at the Dresden Pottery, East Liverpool, by kind permission of the management. It will be readily seen that the shelves are packed closely together, no aisles being neces-

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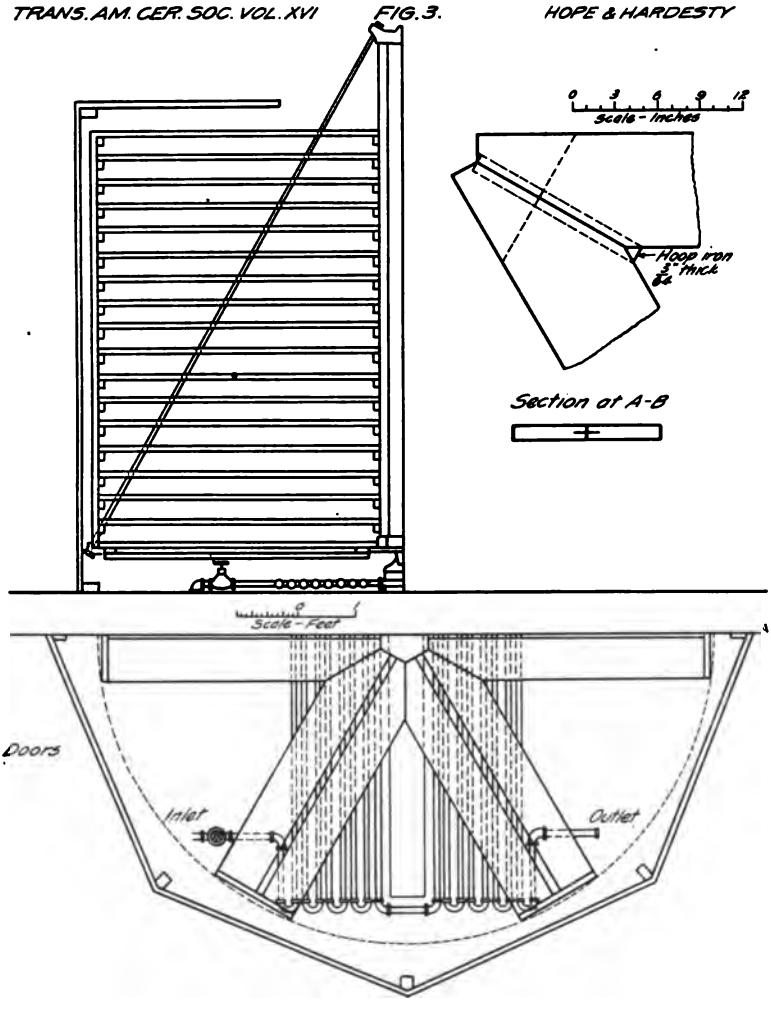

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sary, but on account of drawing out the slide for its full length, it is necessary to provide space double the length of the slide itself.

The following description of a rotary stoveroom applies particularly to those erected in the plant of the Mayer China Co., of Beaver Falls, during the year 1913, and will be rendered more intelligible by reference to Fig. 3. The stoveroom proper, i. e. that part which rotates, is carried by means of a cast iron step on a 4 by 8 timber, lying at right angles to the joists of the floor, and in length nearly equal to the diameter of the stoveroom. As indicated in the drawing, the upper part of which shows the principle of construction and the lower the heating arrangements, a hollow six-sided post made of 2 by 6 hemlock is fitted into the lower casting, the bottom of which ends in the pin of the step. A hexagonal iron cap surmounted by a pin forms the top bearing and holds the post together at the top. The lowest shelf rests at its inner end on an iron rim, 2¼ inches wide, projecting from the lower casting. The outer end is supported by an iron angle piece, through which a half inch rod passes on its way to the upper bearing casting, from which lugs project, thus supporting the rod at its upper end. Boards equal in width to the shelves, and reaching to the top shelf, are set vertically upon the angle casting through which the lower end of the rod passes, the boards being erected in pairs, fastened together by means of 1 by 1½ or 1 by 2 strips, which at the same time serve as supports for the outer ends of the shelves. Corresponding strips are nailed to the center post and support the inner ends of the shelves. The shelves, themselves, may be of any desired width, those in the stoveroom referred to being eight inches. A clearance of about two inches is allowed between the rotary part and the closest part of the outside shell, the latter being built in the form of an octagon in order to save as much space as possible. When saving of room is not considered important the outer frame may be hexagonal. See Fig. 4.

The following comparison of the three principal types of stoverooms will show that so far as space is concerned no very great difference between the three is found to exist:

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FIG. 4

FIG. 5

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Comparison of Space. Ordinary stoveroom, 4 feet wide, by 16 feet long, by 8 feet high, contains 512 cubic feet, and 16 shelves; holds 42⅔ dozens of 7 in. plate molds. 1 cu. ft. per mold.

Drawer or slide stoveroom 1⅛ feet wide, by 16 feet long, by 8 feet high, contains 144 cubic feet, 16 shelves, and holds 10⅔ dozens of 7 in. plate molds. 1⅛ cu. ft. per mold.

Rotary stoveroom, 11 ft. 2 in. diameter of octagon, 8 feet high, 16 58-in. shelves, 872 cubic feet, holds 72 dozens of 7 in. plate molds. 1.01 cu. ft. per mold.

In making a comparison of mold-running distance, it seems fair to assume that both the regular fixed and the rotary rooms are placed four feet behind the jigger, while the slide may come to a distance of three feet on account of the ease with which it may be pushed back, if required. The lateral distance over which the mold runner would travel is assumed to be the same in all cases, though in the case of a single rotary stove room the advantage would lie with the latter, since it would naturally be placed with its center exactly opposite the mold board upon which the filled molds are placed by the jiggerman. Of course, the distance from the center of the stoveroom shelves to the jigger does not represent the whole course over which the mold runner travels, but as he returns to those two points, they offer a fair basis for comparison. The figures given below are based on a day's work of 200 dozen of ware, it being assumed that the mold runner carries two molds each trip:

Comparison of Mold Running Distances. Ordinary stoveroom 16 feet long means 8 feet to center plus 4 feet equals 12 ft. to run twice for 1200 trips equals 5.45 miles per day.

Drawer or slide stoveroom 8 feet long, 4 feet to center plus 3 ft. equals 7 ft. to run twice for 1200 trips equals 3.18 miles per day.

Rotary stoveroom 11 ft., 6 in. diameter, 60 in. shelves equals 2½ feet to center of shelves plus 4 ft. equals 6½ ft. to run twice for 1200 trips equals 2.95 miles per day.

In the case of a rotary stoveroom of average size, say 9 ft. 6 in. having shelves 48 in. long, the total distance would be

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further reduced by nearly a quarter of a mile. This would also be true of the other stoverooms if similarly reduced in length.

Comparison of Cost of Erection. While it has not been possible for the writers to make an accurate estimate of the cost of erecting the stoverooms mentioned, a rough comparison can be made. For equal quantities of molds, it is evident that the shelving must be about equal for any kind of stoveroom, though the lumber used as covering will be less per mold for the slide type than for any other, since all the enclosed space is entirely filled with shelves. The rotary rooms undoubtedly require more lumber and work in the construction than either of the others, especially when isolated or erected in pairs as indicated in clay shop plan No. 2. (See Fig. 7.) The ordinary stoverooms require no castings or machine work and may be left out in this comparison. The cost of installing iron tracks, which would seem to be indispensable to permanent smoothness of working in the case of the slide stoverooms, together with the cost of the iron sheaves and other connections, would probably be greater than boring and turning up the castings for the rotary rooms. The complete cost of a set of the latter, including boring and turning, was quoted at 15 dollars by a local firm.

Approximately the same length of steam pipes would be used in each case, as this is largely determined by the amount of moisture to be evaporated from the clay and damp molds, though of course the air circulation is a very important factor. In practice, the rotary stoverooms have been found to dry somewhat more quickly than the ordinary kind, the air volumes per linear foot of 1 in. pipe (about 5 cu. ft.) being approximately the same. This superiority in drying is probably due to the improved air circulation afforded by the doors at the rear, and by the space around the center post at the top of the room.

Where a single rotary stoveroom is required to serve a jigger, each section should be partitioned off from the others by means of flooring or boards placed vertically between the double row of shelves. By close inspection of Fig. 5 it will be seen that this has been done. The same illustration shows the double shelf

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at the bottom which prevents the molds on the bottom shelf getting burnt by reason of their proximity to the steam pipes.

Owing to the great diversity in sizes of pottery molds, it is evident that the length of the shelves (and consequently the diameter of the whole stoveroom) must be varied in accordance with the measurements of the mold to be used in that particular room. Any attempt at uniformity of size is a serious mistake, as it must inevitably result in loss of space. We have found that an average distance of four feet between the jigger and stoveroom is satisfactory, and this may be decreased if there is no occasion for anyone passing behind the jiggerman. Where a clay truck must pass behind the jiggerman, the distance should be increased.

Figures 6 and 7 show two separate plans for the arrangement of the clay shop of a seven kiln pottery, when equipped with rotary stoverooms, plan No. 1, Fig. 6, being 80 by 150 feet, and No. 2, Fig. 7, 85 by 150 feet. It will be noted, in Fig. 6, the aisle for trucking clay is placed next to the outside wall in accordance with the most recent practice. This saves the annoyance and confusion incident to the constant wheeling of the clay truck behind the jiggermen. The other plan (Fig. 7), is so arranged, that an aisle between each set of stoverooms permits the delivery of clay to the batter-out, thereby preventing the clay truck from passing behind the jiggerman. This aisle also allows plenty of room around the end of the finisher's boards when on the bench; and it should be pointed out in this connection, that the finishers work by the side of the jigger in each case. This arrangement saves a great deal of unnecessary handling of boards, so long as the finisher keeps up with his work, and the ware is fit to finish. When for any reason a finisher is not able to finish the ware as it comes off the molds, several extra benches are provided in various parts of the shop so as to save unnecessary handling of boards. Another advantage of this arrangement is that the finisher is constantly under the eye of the jiggerman, and much careless handling and consequent breakage of ware is thus avoided. In plan No. 1 the stoverooms are grouped together as much as possible, thus saving cost in erection. In plan No. 2 the

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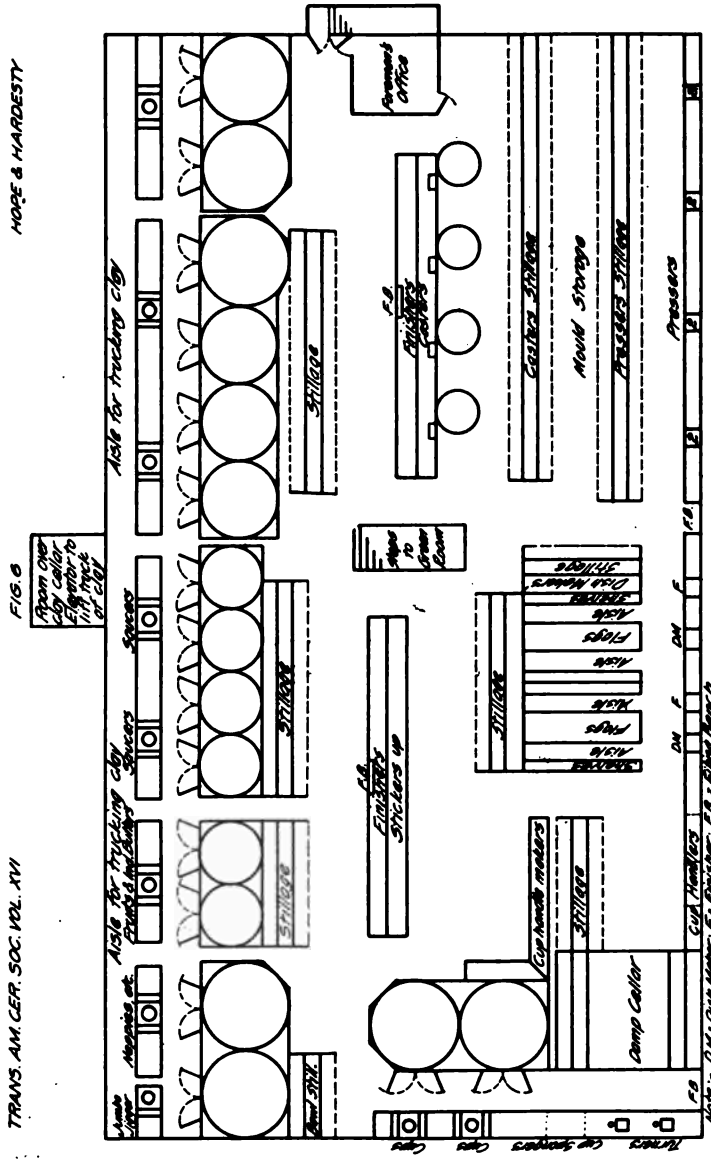
Aisle for trucking clay
Saucers
Aisle for trucking clay
Finished saucers
Saucers
Stillage
Stillage
Stillage

stoverooms are necessarily either single, or in pairs, owing to the system of supplying the batters-out with clay, which system does not permit the clay truck to pass behind the jiggerman.

The two plans are purposely made quite dissimilar so that features of each may be emphasized. It will be found of advantage to provide doors at the side or back of any rotary stoveroom, especially since there will be found room here for mold storage, and the rooms can be much more quickly filled and emptied than if the molds had to be carried round to the front, as is necessary with the common type of rooms. Mention has already been made of the aisle for trucking clay in front of the jigger, shown on plan No. 1, but the system of loading the clay truck in the sliphouse and bringing it up on a platform elevator as indicated in the same plan, appears to the writers far preferable to the usual method of sending up each lump separately on a belt elevator.

While the rotary stoverooms possess certain advantages over the slide or drawer type, the latter are far preferable for square or oval dishes. If the slides are so arranged that every third one contains flags, then when both the latter and the slide containing the molds and ware are pulled out at the same time, the dishmaker can stand betwen the two and transfer the ware from the molds to the flags without the inconvenience and discomfort attending the work when it has to be performed in the hot and rather dark stoveroom, as is usually the case at present. If these slides are made 12 in., 15 in. and 18 in. wide, and placed thus consecutively, first three containing molds, then the same number containing flags, a practically uniform distance will be maintained between the molds and flags. This arrangement can be seen by reference to plan No. 2.

In order to make details of the two clay shop plans intelligible, it should be stated that the round tables for casters are fully described elsewhere in this volume, and that the small spaces allotted to the finishers for filing benches are a precaution frequently ignored, and yet the lack of some such precaution is often made evident by the iron specks in the body. A magnet

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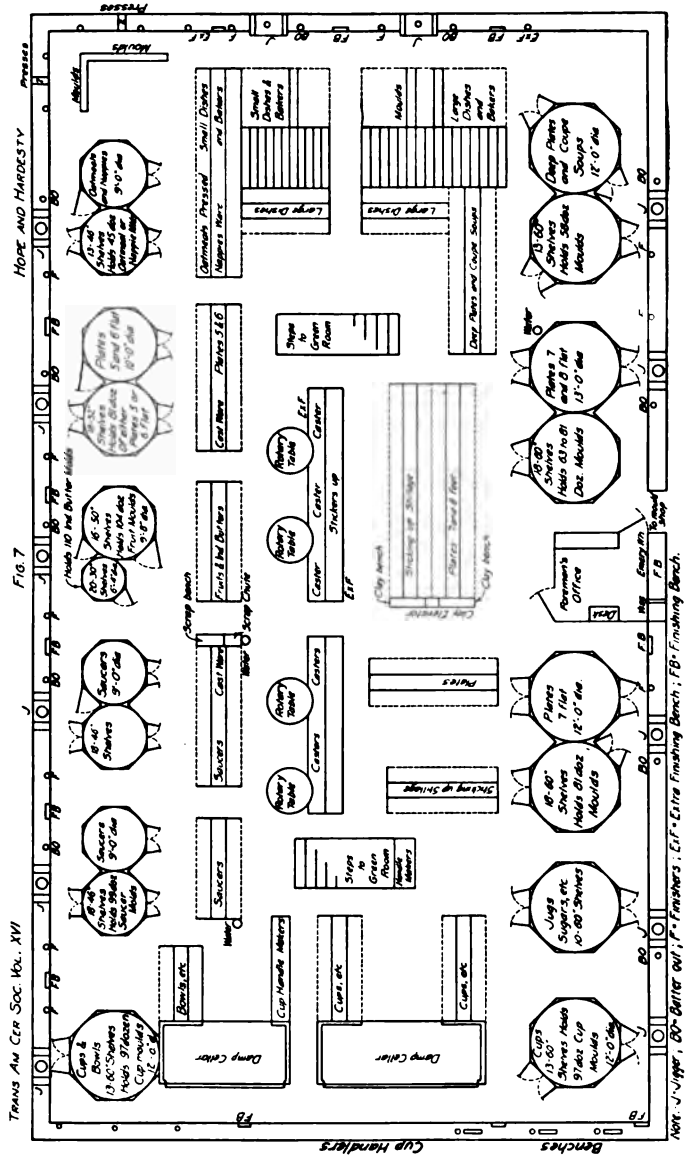
Trans Am Cer Soc. Vol. XVI
Fig. 7
Hope and Hardesty
Presses
Moulds
Cup Handlers
Benches
Damp Cellar
Cups & Bowls
Saucers
Plates
Stacking up Shelves
Rotary Table
Casters
Stacking up
Steps to Green Room
Scrap Bench
Scrap Chute
Fruits & Ind Butters
Cent Hers
Plates 5 & 6
Plates 7 & 8
Plates 7 Flat
Plates Tand & Flat
Large Dishes
Small Dishes
Large Dishes
Deep Plates and Coupe Soups
Deep Plates and Coupe Soups
Foreman's Office
Clay Bench
Clay Hence
Clay Elevator
Steps to Green Room
Water
Note: J=Jigger, BO=Better Off; F=Finishers; E.F=Extra Finishing Bench; F.B=Finishing Bench.

kept in the bottom of such filing boxes would aid materially in preventing the filings from becoming scattered.

An objection, sometimes urged against rotary stoverooms, is that too much weight is concentrated at one point, thereby rendering dangerous the erection of such stoverooms on an upper floor. A little calculation will suffice to prove that such fears are groundless, as single 2 by 12 pine joists on 12 in. centers will hold three or four times the weight of a 10 or 12 foot diameter stoveroom, provided, of course, that the timber upon which the step rests is almost as long as the diameter of the room. It is, however, a wise precaution to double or triple the joists immediately under the rooms when new construction is undertaken.

In conclusion, the writers wish to state that both the rotary and the slide or drawer stoverooms are so decided an improvement over the prevailing type that either one or the other should be adopted wherever possible, the particular one adopted depending largely upon width or length of the space at one's disposal.

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DESIGNS OF SEVEN TEST KILNS

BY R. T. STULL AND R. K. HURSH, URBANA, ILLINOIS

In presenting the designs of these test kiins, no claims are made to original ideas. In the design of each kiln, an attempt has been made to combine well-known principles in such a manner as to best meet the conditions and requirements which the kiln is to meet.

All flues leading from the kilns are placed under the floor. These connect with two main flues 15 in. wide by 30 in. deep, which in turn connect with a 60 ft. stack. Kiln represented by Figs. 1 and 2 is of the down-draft, open fire type, provided with two fire boxes. The fire boxes are short and wide, facilitating easy cleaning and prolonged life of grate bars. The kiln is provided with a flue system so that forced draft may be applied either above or below the grates. The kiln has been in use over two years and has been fired repeatedly to cone 16. It has a surplus of draft so that it has not been necessary to use forced draft to reach high temperatures.

In Figs. 3 and 4 is shown a rectanglar down-draft muffle kiln. The muffle is 2 ft. by 3 ft. and 3 ft. to the spring. The muffle walls are laid with hollow blocks beveled at the corners in order to give greater radiation surface. The same size and style of fire box is used in this kiln as in the former one. The kiln has been burned to cone 8 in twelve hours. After two years of use, it is in excellent condition.

Figures 5 and 6 represent a round down-draft open fire kiln. Fuel oil, delivered to the kiln under 5 lbs. pressure, and air at 2 lbs. are used in firing. The four burners lead tangentially into a combustion ring. The fire gases pass up over a circular flash wall and down through the perforated floor.

The crown is removable and is raised and lowered by a three ton chain hoist running on a track. This arrangement permits of easy and quick setting and eliminates the troublesome cold doorway. The temperature and kiln atmosphere can be governed very closely. The kiln has been in use for more than a

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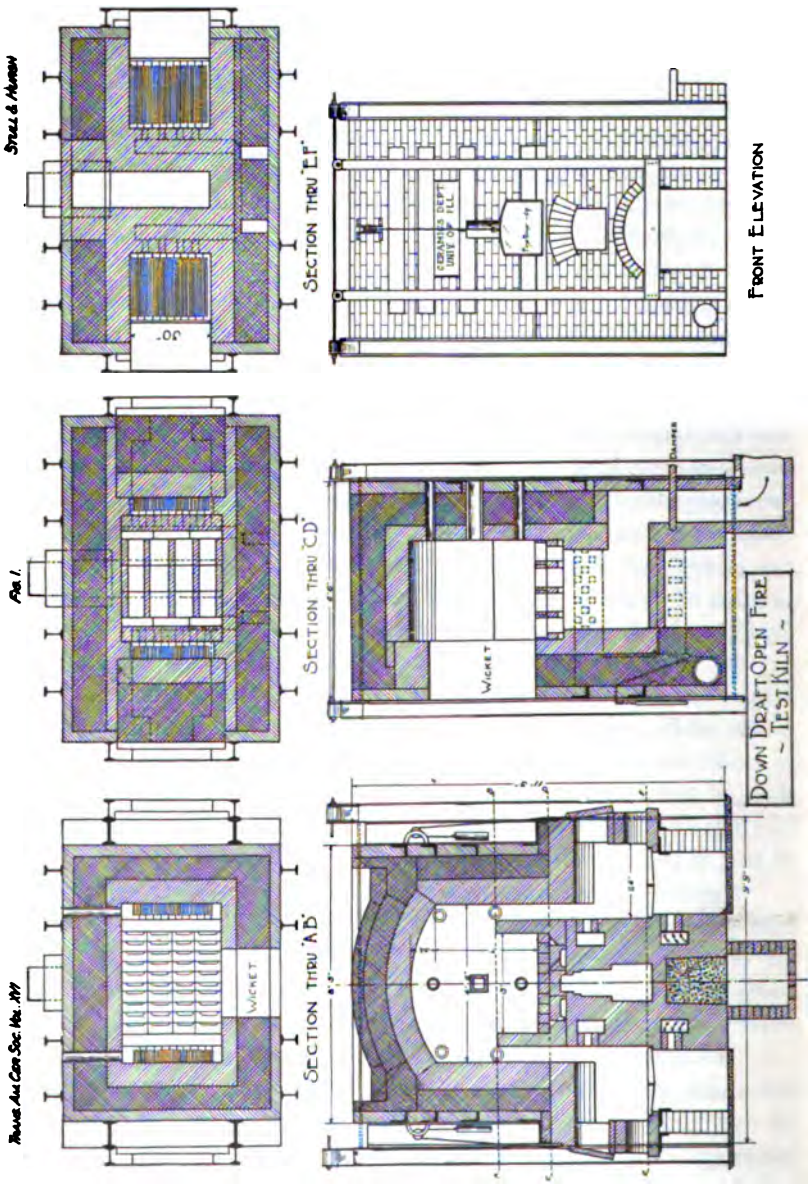

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year. Although it is capable of attaining very high temperatures, there has been no occasion to fire it above cone 8. This temperature has been attained with only two burners in use.

Figures 7 and 8: Open fire, down-draft kiln: The kiln is fired by gas and compressed air, both being preheated in coils

FIG. 2

of wrought iron pipe suspended in the out-going flue. The flue is provided with an opening just below the damper. Through this, air can be admitted in order to prevent over-heating of the coils. The kiln is fired by ten burners made from ordinary pipe fittings. Each burner is about the size of an ordinary Bunsen blast lamp. The kiln has been fired to cone 14 in six hours.

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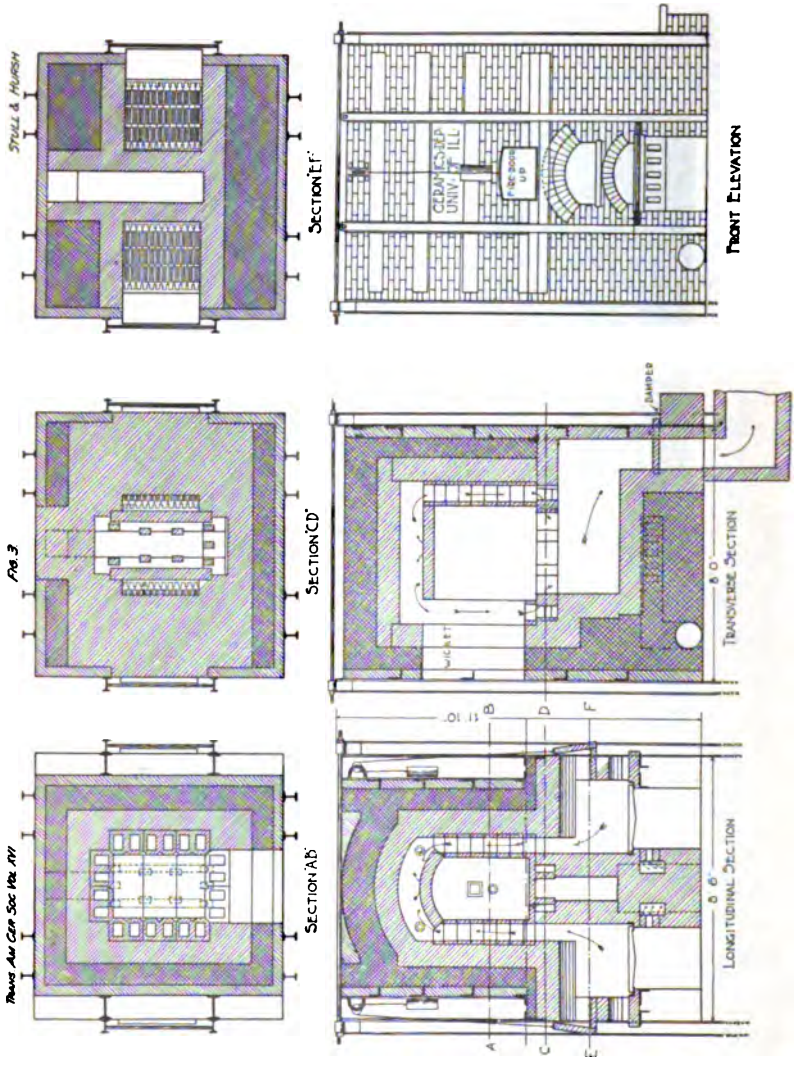

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The setting chamber is 12 in. by 22 in. by 9 in. to the spring, and 4 in. rise. The kiln is especially adapted to clay testing. Two plugs in the crown, one in the back and one in the wicket, are provided for drawing trials.

FIG. 4

Figure 9: Battery of three calcining kilns: Each unit is fired by fuel oil and compressed air. The combustion chamber at the top is cylindrical in form, the flame entering tangentially. Each unit is provided with two calcining chambers. The kilns are designed especially for burning small batches of Portland cement, and for calcining clays and dry colors. The material

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to be calcined may be placed on the bottom plate of the chamber or in covered flat tile saggers.

Figure 10: Twin muffle kiln: The kiln was designed especially for firing enamels for metals and overglaze colors. Each muffle is heated by two gas burners, the air being preheated in the recuperator below the muffle. The gas passes in horizontally and meets the air coming up from the recuperator. The flame passes back to the opposite end of the muffle then turns and passes twice around the muffle to the center and down into the recuperator. The hottest parts of the flames from the two burners applied to each muffle, moving in opposite directions, encircle the muffle ends first, then encircle the middle, thereby neutralizing the "cold end" effect and giving a more uniform muffle temperature.

Figure 11: Battery of four drop-frit furnaces: Each furnace is fired by two small gas burners made from pipe fittings. The gas and air are preheated in wrought iron pipe coils placed in the outgoing flue. The flames pass into the combustion ring tangentially, then pass over a flash ring and down around the crucible. The frit pan underneath when filled with water forms a "water seal." The bottom of the pan is curved so that the frit can be raked out, making it unnecessary to remove the pan. The principal objection in the construction of the furnace is that the frit pan is too close to the fire. It should be placed about two to three courses of brick lower in order to obviate the rapid evaporation of the water and the burning of the top of the pan.

Ceramic Laboratories,
University of Illinois

DISCUSSION

Mr. Blair: Will Professor Stull give us an idea of the cost of burning that first kiln?

Prof. Stull: Yes. I can give you an idea of the cost. Like Professor Bleininger, I did not want to scare you to death with the figures. A large fill was made on the present site of the new kiln house. In building the foundations for these kilns, it was necessary to go down so deep to get solid ground that it brought

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up the costs enormously. The cost of that part below ground is nearly as much as that above ground. The first furnace shown cost between seven hundred and eight hundred dollars, that is, as near as I can remember. The figure given is for the kiln complete, including foundation, flues, iron work and all. Plenty of iron work has been placed on all kilns with a view to having them well braced.

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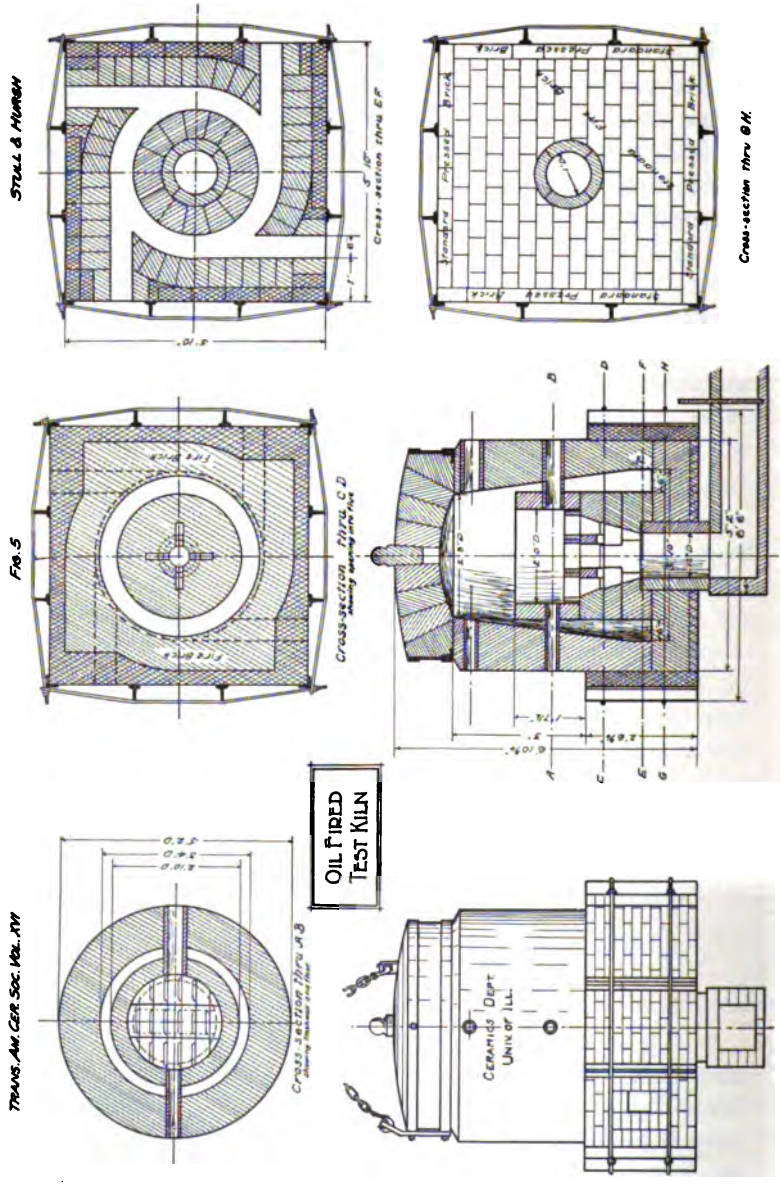

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FIG. 6

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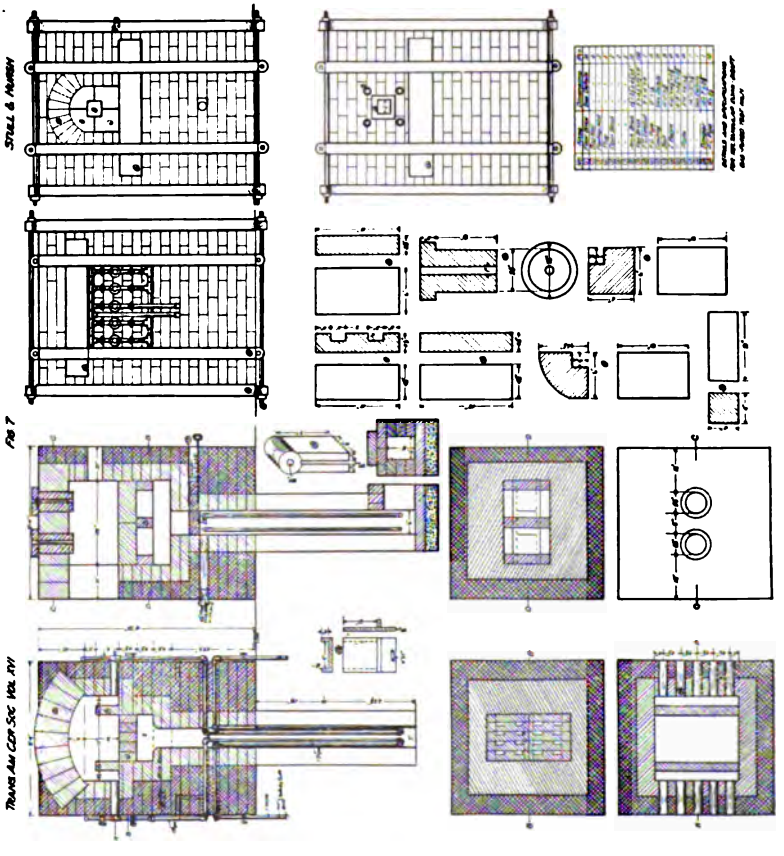

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FIG. 8

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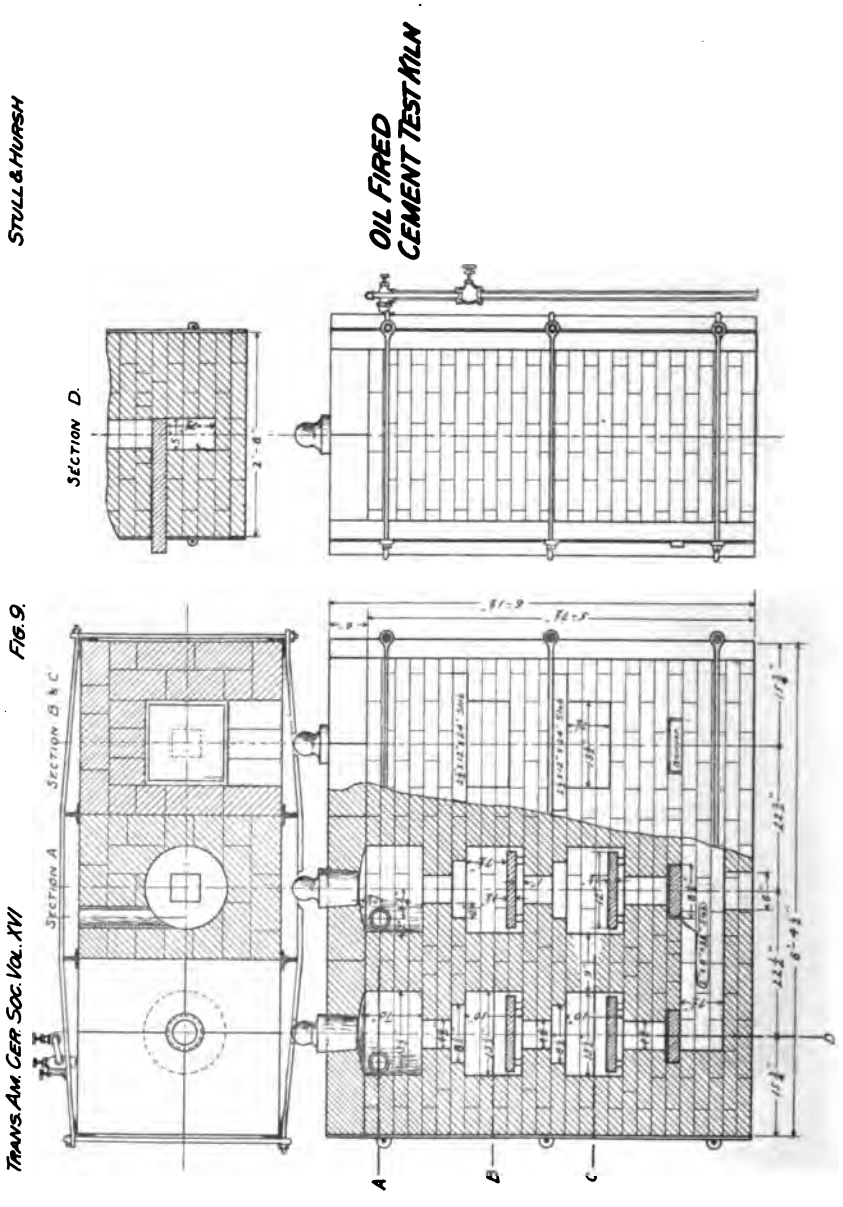

TRANS. AM. CER. SOC. VOL. XVI FIG. 9.

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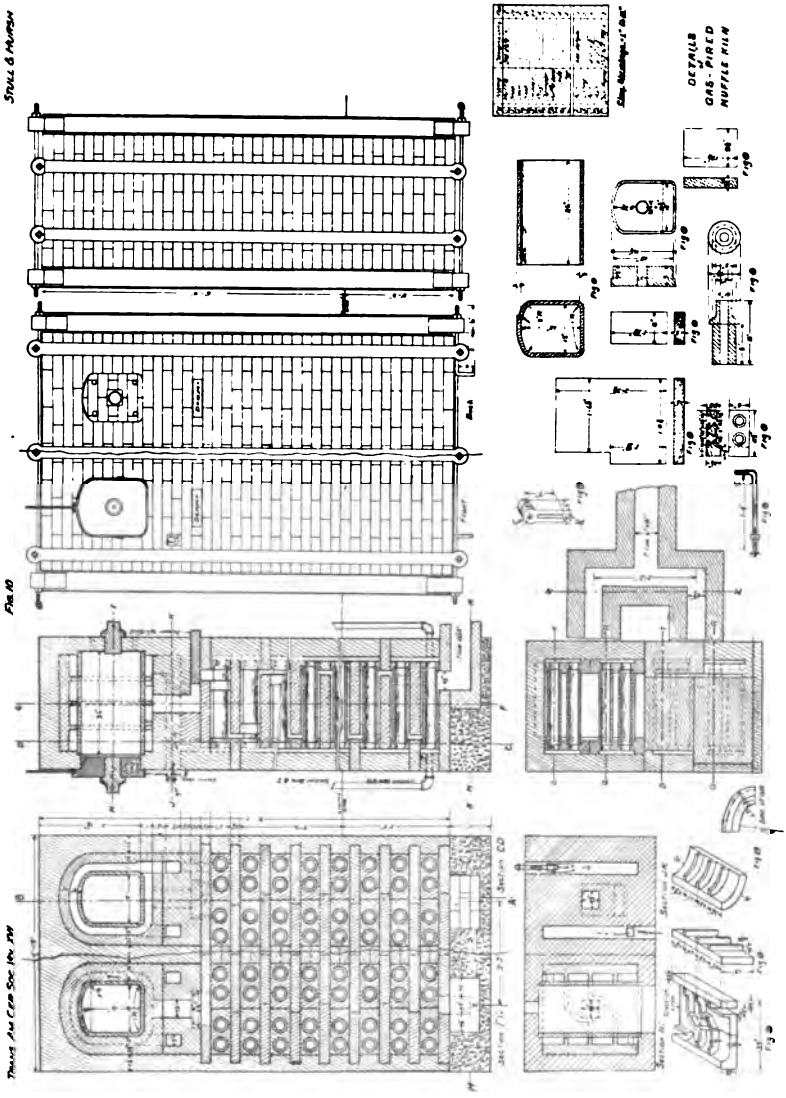

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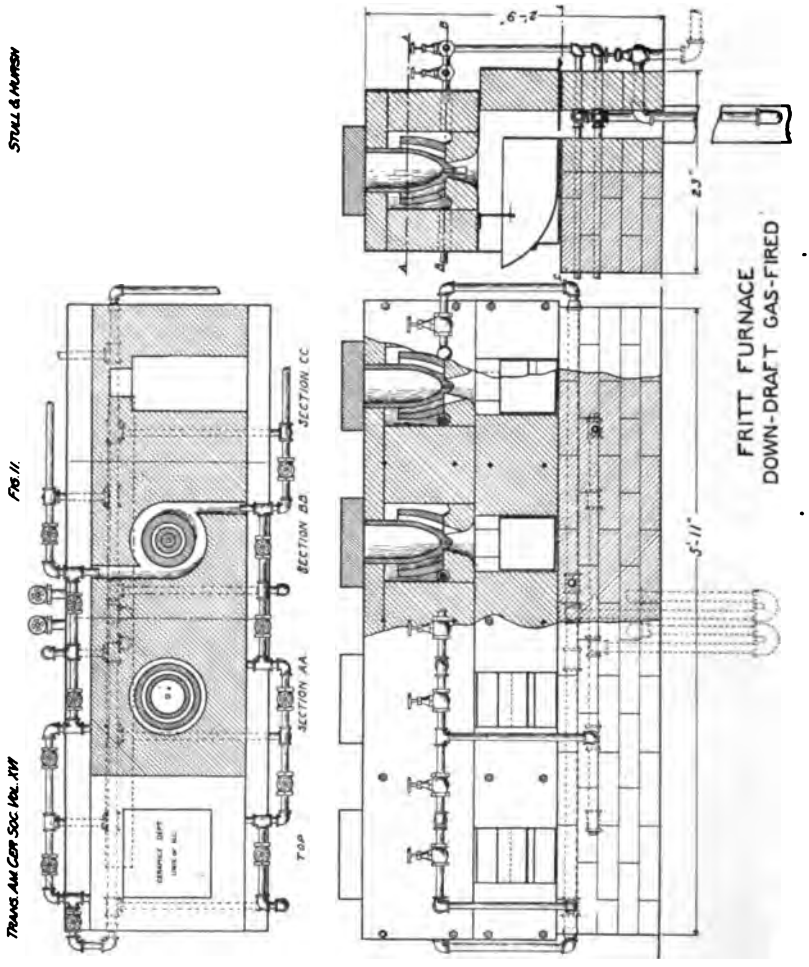

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HINTS ON EXPERIMENTAL ENAMEL MAKING

BY W. ANGUS DENMEAD

The following notes are drawn from the writer's experience in the making of enamels for the coating of reflectors, drawn steel tubing, castings, etc. The hints are elementary in the extreme, and most of them are known to enamel-makers, but it is hoped they may be useful to a beginner in his attempts to produce low temperature enamels. By low temperature enamels I mean those maturing between 700° and 1000°C.

Furnace. A sketch in shown in Figure 1 of a most economical and efficient frit furnace. The advantages are ease of binding, long life, and control of conditions through the use of compressed air and gas. The furnace bottom is placed high to enable one to look up under the same without getting on the knees. This is a most desirable feature that will not be appreciated until a furnace of this type is made. In Figure 4 a furnace of this type is shown; in this case, however, the bottom is placed too low.

Crucible Support. The use of a crucible support (See Fig. 2) is of great advantage, as it prevents all trouble resulting from the breaking of a crucible and the flooding of the bottom of the furnace with molten enamel. The crucible support can be easily chipped out, and a new one inserted in case of accident. If, however, the crucible were placed on the furnace floor, a large amount of labor would be necessary to clean the furnace after such an accident, and if the furnace were not cleaned the next crucible would stick to the floor as soon as the furnace reached the melting temperature of the spilled enamel.

These supports can be made in a few minutes by chipping a graphite crucible to shape. A support made from this material lasts much longer than those made from fireclay. It may be necessary to avoid the use of a graphite bottom in the manufacture of an enamel which is very sensitive to reduction. We have, however, found no case of a graphite support harming any frit now in use at our factory.

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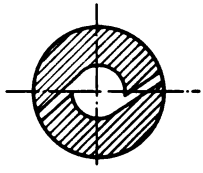
TRANS. AM. CER. SOC. VOL XVI FIG. I DENMEAD



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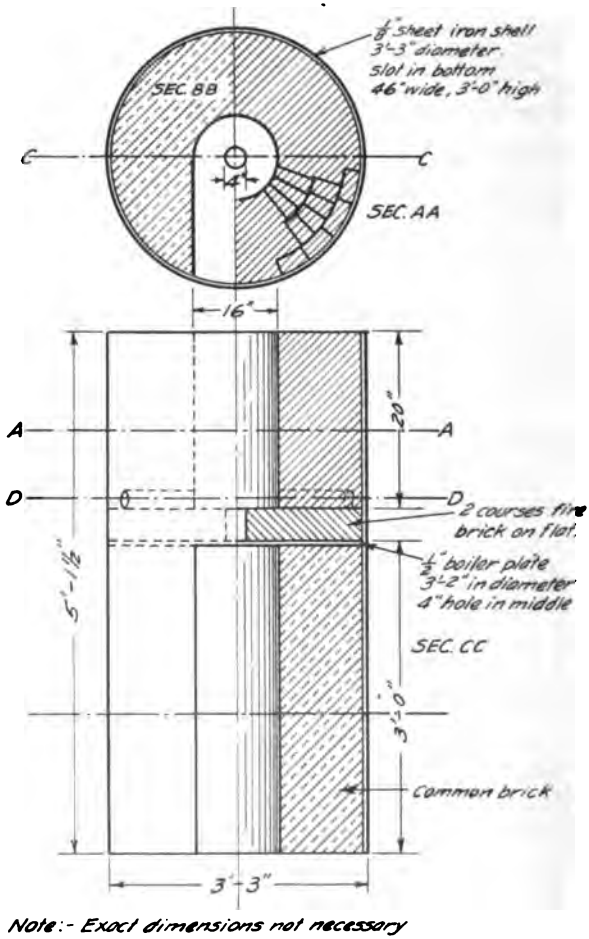

Note:- Exact dimensions not necessary

FRIT FURNACE

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Means of Prolonging Life of Crucible. It will be found that a crucible will last much longer if:

1. It is heated slowly.
2. It is cooled slowly.
3. A charge is not put into the crucible until the crucible is red-hot.

The means of producing the first condition is self-evident.

It has been found that more crucibles break in cooling than in heating. To cut down the loss from this cause, fireclay slabs should be used to cover the top of the furnace completely while the crucible is cooling.

A charging scoop made of copper with a long iron handle will be found of great advantage in charging the red-hot crucible, and its use will prevent the loss of raw materials or the burning of the hands. It was found that copper was best suited for the scoop, as the powdered raw material stuck to it less than any other metal tried.

Controlling Degree of Combination. It will be found that the viscosity of a molten frit is important as a partial indication of the extent of fusion or of combination. In order to insure the frit having a longer or shorter firing period in the furnace, a hole of suitable size may be drilled in the crucible bottom. In general, for enamel frits, the hole should not be over one quarter inch in diameter; if the hole is larger, the frit will run before complete combination of the raw materials is effected. The size of this hole will also increase quite rapidly as the crucible is used. To insure complete combination in frits of very low viscosity, it will be found necessary to either re-frit, or frit in a crucible without a hole.

How to Drill a Crucible. This operation, apparently quite difficult to the novice, may be easily accomplished. First grind your drill to a slightly sharper point than that used when drilling steel, making sure that you get the cutting edges sharp. Next heat the drill to red heat and plunge it into water. To drill a crucible, an electrically driven drill is preferable, owing to the ease of increasing or decreasing the power applied, but with practice the drilling may be done on any drill press. The sur-

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face of the crucible should be broken at the point where the hole is to be drilled. This may be accomplished by light taps of any blunt instrument.

Now start the drill revolving slowly and keep just as much pressure on it as is possible without stopping the drill. If this is done as directed, the drill will go through the crucible almost as readily as through wood. It is important to prevent the drill from revolving too rapidly, or stopping, as in either case the

FIG. 4

drill will dull rapidly. In case the drill stops or revolves too rapidly, it should be withdrawn immediately and examined, since the point of the drill may be easily melted in this manner, and the drill ruined. After acquiring the knack, three or four crucibles may be drilled before sharpening and tempering the drill.

Crushing the Frit. In making experimental batches, it will be found advisable to crush the frit to 10 mesh before grinding in the ball mill, as this will be a great aid in obtaining duplica-

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tion of results and proper fineness of grinding. In case it is impracticable to do this, the frit should be ground in a ball mill, the mill opened every half hour or so, and all 10 mesh material screened out. If the enamel is to be used in the dry form, the above is not necessary, the material may be sieved through the last screen when the mill is opened. We use a small jaw crusher to crush the frit, and have not found that the small amount of iron worn off affects the color.

Addition of Clay in Grinding. Most frits are ground with a small amount of clay (varying from 2 to 20 percent) when they are to be applied by dipping or spraying. If raw clay is used in the enamel, do not add it to the experimental batch until the last half hour of grinding; this will prevent cracks in the enamel when applied to the ware provided the enamel proper is not too finely ground. We find no advantage in grinding enamels finer than 80 mesh, when they are to be applied by the wet process, though it is probably advantageous to grind them close to 200 mesh when the enamel is to be applied by dusting.

Keeping the Enamel in Suspension. If the enamel settles rapidly, add one ounce of a hot concentrated solution of borax to each gallon of enamel, and the solid particles will remain in suspension much better. We have found borax to be the best material for this purpose, though various factories use other materials. In case the enamel contains no raw clay the addition of borax will not be effective. In cases where we do not add clay to our enamel, we sometimes arrange to dip the ware directly in a small blunger in order to insure the enamel's suspension at all times.

Keeping the Viscosity Uniform. Where enamels are to be applied by dipping or spraying it will be found quite important to maintain a constant viscosity, as upon this, rather than upon density, depends the thickness of coating left on the piece after dipping or spraying. After experimenting, we made what I call a "viscosity spoon" (Fig. 3). Quite a crude affair, but it answers our purpose admirably. We mix a batch of enamel to the desired viscosity (determined by testing out on the ware). We then made a long-handled stirring spoon of copper, the handle

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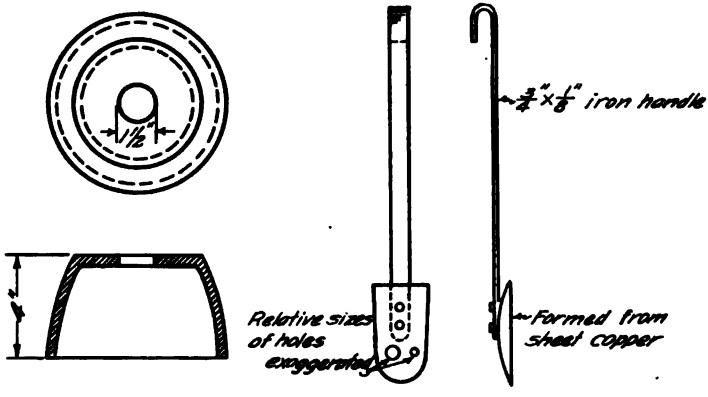
made of iron. Two holes are drilled in the spoon through only one of which the enamel will flow when the desired viscosity is obtained. If we do not strike the right sized holes the first time we solder them up and drill others until the right sized holes are obtained. This device is made in the form of a spoon with long handle so that it may be used as a stirring spoon as well as for the above purpose.

TRANS. AM. CER. SOC. VOL. XVI DENMEAD



CRUCIBLE SUPPORT FIG. 2 VISCOSITY SPOON FIG. 3

Changing the Coefficient of Expansion. In touching upon this subject I realize I am tackling a delicate one, and rather than call forth criticism for rash statements will explain that I do not claim Table I as iron-clad, nor do I claim results may be predicted by its use. By the use of Table I, I have been able to influence the coefficient of expansion within reasonable limits, except where unusual conditions were present, such as the presence of the ingredient in large quantity in the enamel before additions were made:

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TABLE I—COEFFICIENTS OF EXPANSION

Na_2O	10.0
K_2O	8.5
Al_2O_3	5.0
CaO	5.0
PbO	3.0
BaO	3.0
SiO_2	0.8
B_2O_3	0.1

I procured this table from a chemical journal and was very skeptical as to its being of any value, until repeated tests showed that it was. In the table, the oxides are arranged in the order of their ability to raise the coefficient of expansion, Na_2O being the highest. The numerals give their relative ability to raise the same, but of course additions of the last members would tend to lower the coefficient of expansion of most enamels.

DISCUSSION

Mr. Landrum: This is a clever method for getting the viscosity of an enamel slip. The enameler has always used a spoon to drip, judging by the way the drops come off just when the slip is right. The use of a large and small hole in the spoon is a clever means of attacking the problem.

Regarding the tables of coefficients of expansion, I might say that I have given a long series of other materials not mentioned in this table. It is peculiar that while the coefficient of expansion of iron is around 400, the ground coats that I have been able to use to the best advantage have a coefficient of expansion much smaller, say 300. When I get an enamel with a coefficient of expansion, running near that of sheet steel of 27 gauge, the enamels will stick very badly. I have never been able to understand why we should not get a better sticking enamel, if we had the coefficient of expansion the same as the steel itself.

Mr. Potts: The relation of coefficients of expansion to the other physical properties of fused bodies has been discussed to great length in the past few years. The speaker himself has taken part in such discussions, and in the necessary study has come to the conclusion that there is nothing strange or remark-

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able in Mr. Landrum's experience. In some work carried on at the Ohio State University a few years ago, we found on consulting foreign literature, in *Sprechsaal* No. 43, 1910, pages 624 to 638, an article by Carl Testmann entitled: *"Die Bedeutung des Ausdehnungskoefficienten in der Keramick."* In this paper is given a discussion of work done by Coupeau upon the coefficient of expansion of a variety of types of glazes, and also a table showing the results of work done by Tostmann himself. In Tostmann's work, he added 2 percent of the materials commonly used in the clay industry, to a standard glaze, and then upon the glaze having been fused, he measured the coefficient of expansion of rods formed by this glaze containing the various additions. Commenting on this table, he draws attention to the fact that in almost all of the well known instances this data is contrary to what would be expected from the function Seger assigns to the various oxides in his rules for correcting glaze-fit. And because of this, and the fact the data do not agree with the usually accepted coefficient expansion theory of Seger, he has little faith in the significance of his own data, even though it agrees in the main with the data obtained by Coupeau. This data, as well as the experience of many other investigators to the list of whom Mr. Landrum's name should now be added, bears out the statement frequently made, that the coefficient of expansion does not affect the properties of an enamel or a glaze in the manner usually assigned to it, and that there are other factors that are much more potent in bringing the observed results.

Mr. Denmead: I think that Mr. Potts must qualify his statements somewhat. I believe he would, if he should attempt to enamel something with a quarter inch of enamel. In the practical insulation business, he would find that the coefficient of expansion is most important and the hardest problem to solve.

Prof. Silverman: There is a point regarding Mr. Landrum's experience with an enamel of a greater coefficient of expansion than that of the thing to be enamelled on which I should like to pass an opinion. I have had no experience with enamels but it looks as if an enamel with a slightly greater coefficient of expansion than the metal might exert pressure on the metallic

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surface and bring about a more intimate contact with it because of its greater contraction.

Mr. Watts: Havas of the Technical School of Karlsruhe, who has probably done as much work in enamels as anyone else in the world, in connection with Mayer, told me that from his experience with enamels over articles of both steel and cast iron, he believed that the coefficient of elasticity was very vital. His investigations of the coefficient of expansion, which he determined for all his enamels, has led him to believe that the coefficient of expansion was of less importance than the coefficient of elasticity. Whether he has changed his opinion or not, I do not know. He had had a vast experience in the operation of iron and steel enamels, both from the technical and practical side.

Mr. Landrum: I should like to ask whether there has been worked out any table for the coefficient of elasticity, or just what that term would mean?

Mr. Watts: Mayer of the Technical School at Karlsruhe has done a lot of work on that subject, and it is in the form of a thesis.

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DEFORMATION TEMPERATURES OF SOME PORCELAIN GLAZES

R. T. STULL AND W. L. HOWAT, URBANA, ILL.

The group of glazes studied comprises ten horizontal series designated by letters from A to J, each series consisting of ten members. The group of one hundred members covers the following limits represented by the four corner glazes:

TABLE I—FORMULA OF CORNER GLAZES

GLAZE	K_2O	CaO	Al_2O_3	SiO_2
A-1	0.3	0.7	0.40	2.0
A-10	0.3	0.7	0.40	6.5
J-1	0.3	0.7	0.85	2.0
J-10	0.3	0.7	0.85	6.5

TABLE II—BATCH WEIGHTS

	BRANDYWINE FELDSPAR	WHITING	ENG. NO. 20 BALL CLAY	N. C. KAOLIN	FLINT	$Al_2(OH)_6$
A-1	167.4	70.0	12.9	12.9	.....	....
A-10	167.4	70.0	12.9	12.9	270.0	....
J-1	167.4	70.0	12.9	12.9	.....	70.2
J-10	167.4	70.0	70.9	70.9	216.0	....

Different members in the group were made by molecular blending of the four extremes. These were applied to bisque wall tile, set in saggers in a down draft kiln and burned to cone 9 in 40 hours.

Cones were also made from the glazes and their deformation temperatures determined in a platinum resistance furnace, the temperatures being measured by a platinum, platinum-rhodium thermocouple and a Leeds-Northrup direct reading potentiometer, (accurate to 3°C).

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The time-temperature curve followed in all determinations is shown in Figure 1. The temperature was raised to 1200°C. in 120 minutes. Beyond this the temperature rise was 2½ degrees per minute. A number of deformation tests made on duplicate Seger cones gave the following results: cone 4—1212°C., cone 6—1255°C., cone 8—1290°C.

Deformation-temperature readings were made on two or more cones of each glaze. The variation was rarely over 5°C., and in the majority of tests, duplicate cones gave the same temperature readings.

TABLE III—DEFORMATION TEMPERATURES COVERING THE LIMITS

$$\left.\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 0.40 \text{ to } 0.85\ Al_2O_3\ :\ 2.0 \text{ to } 6.5\ SiO_2$$

	1	2	3	4	5	6	7	8	9	10	MOLECULES Al_2O_3
J	1277	1246	1232	1235	1247	1252	1248	1260	1267	1265	0.85
I	1275	1240	1228	1230	1240	1235	1245	1247	1250	1252	0.80
H	1272	1245	1232	1230	1230	1232	1235	1235	1245	1245	0.75
G	1272	1240	1228	1228	1232	1232	1233	1237	1235	1247	0.70
F	1267	1238	1225	1225	1225	1225	1228	1235	1235	1245	0.65
E	1232	1225	1225	1222	1220	1225	1228	1235	1245	1245	0.60
D	1230	1225	1225	1227	1230	1230	1240	1245	1248	1252	0.55
C	1232	1228	1228	1228	1228	1230	1240	1248	1252	1255	0.50
B	1235	1230	1228	1233	1235	1245	1254	1252	1257	1270	0.45
A	1232	1232	1240	1245	1245	1255	1255	1268	1272	1277	0.40
MOLECULES SiO_2	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	

The average temperature readings for two or more cones of each glaze of the group are given in Table III. The results of the burn and the iso-deformation lines are represented graphically in Figure 2, the deformation-temperature being indicated in degrees centigrade on each line.

The RO is constant for all glazes. The molecular variations of SiO_2 are plotted along the abscissa and the molecular variations of Al_2O_3 on the ordinate.

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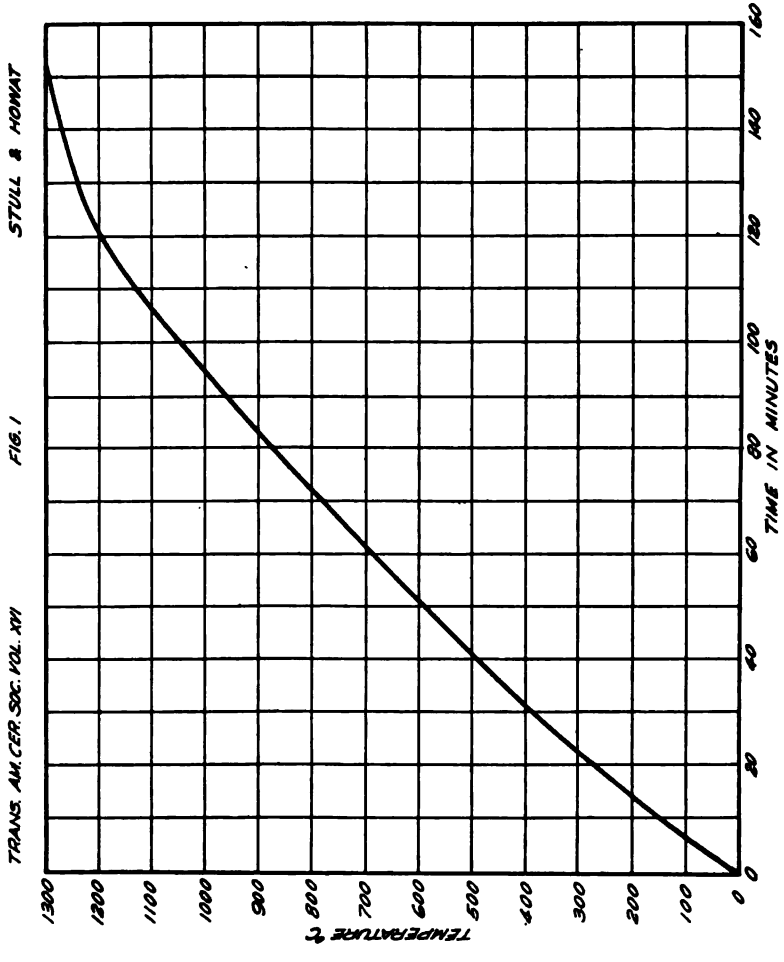

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In the lower right corner are the devitrified glazes between the limits:

$$RO,\ 0.4\ Al_2O_3,\ 5.0\ SiO_2$$
$$RO,\ 0.4\ Al_2O_3,\ 6.5\ SiO_2$$
$$RO,\ 0.6\ Al_2O_3,\ 6.5\ SiO_2$$

In the lower portion of the devitrified area the glazes were crazed. In the center of the field are the bright glazes which were considered matured. Bright glazes which were crazed are found in the lower left corner within the limits:

$$RO,\ 0.4\ Al_2O_3,\ 2.5\ SiO_2$$
$$RO,\ 0.4\ Al_2O_3,\ 2.0\ SiO_2$$
$$RO,\ 0.5\ Al_2O_3,\ 2.0\ SiO_2$$

At the left of the field a small group of matured mats are found between limits:

$$RO,\ 0.55\ Al_2O_3,\ 2.0\ SiO_2$$
$$RO,\ 0.70\ Al_2O_3,\ 2.0\ SiO_2$$
$$RO,\ 0.65\ Al_2O_3,\ 2.5\ SiO_2$$

In the upper part of the field the glazes were under fired.

The difference between max and min deformation temperatures is 57°C., the softest one deforming at 1220°C. having the formula, RO, 0.6 Al_2O_3, 4.0 SiO_2. The member at the upper left corner (RO, 0.85 Al_2O_3, 2.0 SiO_2) and the one at the lower right corner (RO, 0.4 Al_2O_3, 6.5 SiO_2) deformed at the max temperature 1277°C.

Each horizontal series may be considered as being composed of the components, glaze and SiO_2. The broken line CD passes through the deformation-eutectic of each of the ten glaze—SiO_2 series. In a vertical direction, consider each series made up of glaze and Al_2O_3, the dotted line EF represents the deformation-eutectic axis of the ten glaze—Al_2O_3 series.

These two axes (CD and EF) cross at the point of lowest deformation temperature (group eutectic). Its deformation temperature is ten degrees higher than the indicated temperature of Seger cone 4. The glazes whose formulae correspond to cones 4, 5 and 6 deformed at 1228°C, 1240°C and 1245°C respectively.

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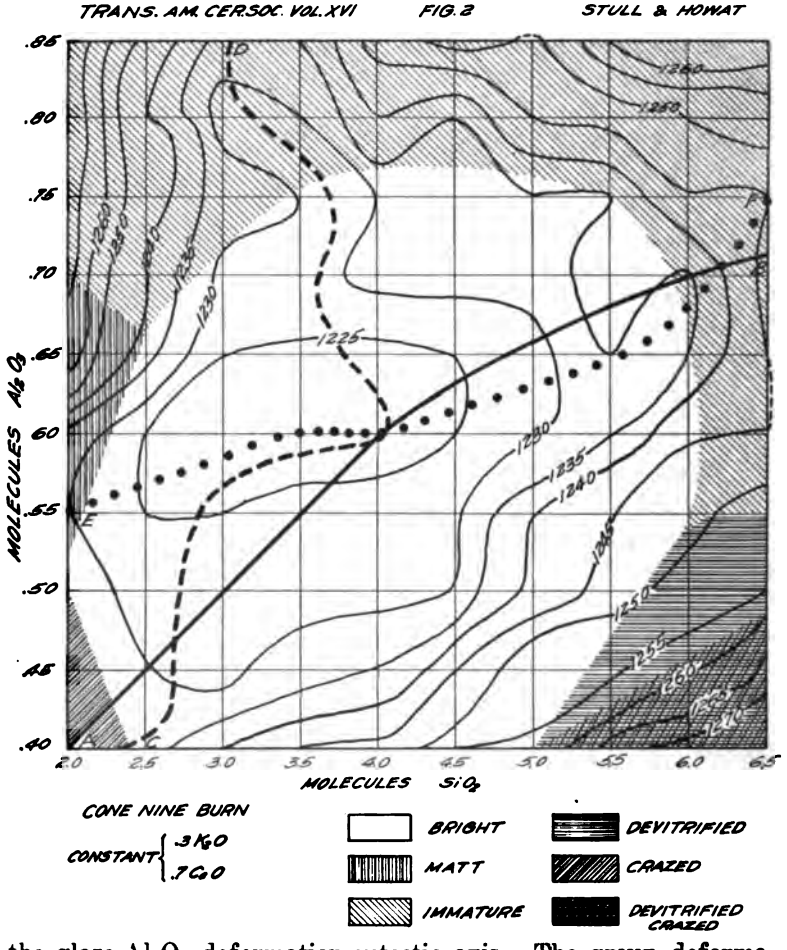
The line AB is the high gloss axis plotted according to the appearance of the glazed trials. The gloss axis follows roughly parallel to the glaze-SiO_2, deformation-eutectic axis up to the group eutectic. Beyond this point it deflects and follows along



the glaze-Al_2O_3 deformation-eutectic axis. The group deformation-eutectic lies near the center of the field of best glazes, and the quality of the glazes decreases in all direction away from this eutectic point. The general formulae of the best glazes as shown by the trials are:

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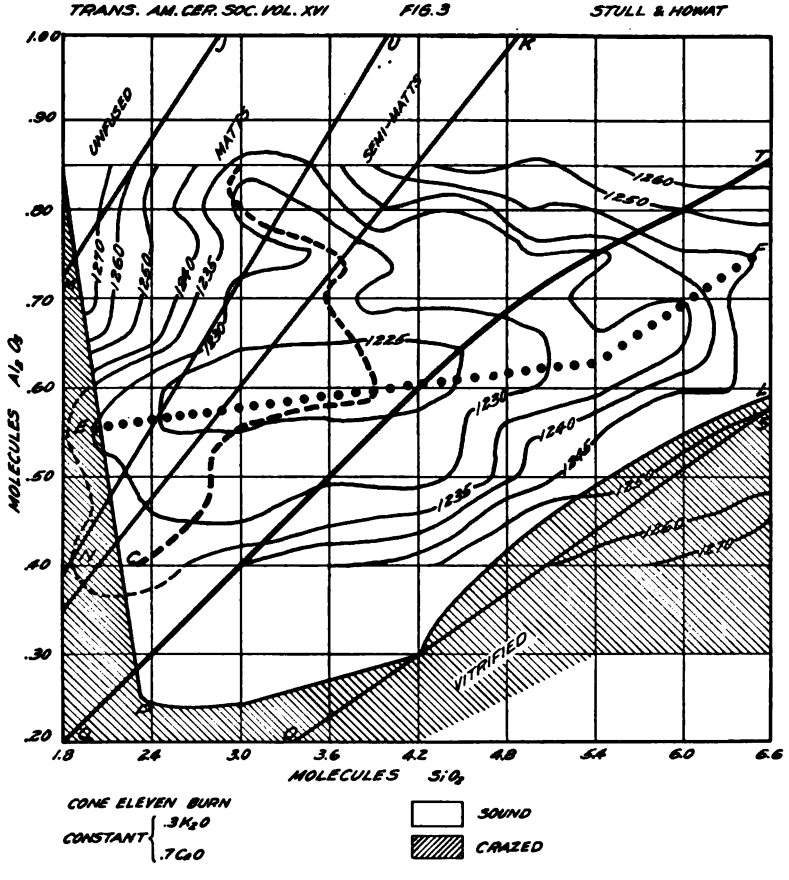
RO-0.60 Al_2O_3 4.0 SiO_2 Deformation temp. = 1220°C.
RO-0.55 Al_2O_3 3.5 SiO_2 Deformation temp. = 1227°C.
RO-0.55 Al_2O_3 4.0 SiO_2 Deformation temp. = 1230°C.
RO-0.60 Al_2O_3 3.5 SiO_2 Deformation temp. = 1222°C.



The difference between the deformation-temperatures of these glazes and the temperature to which they were fired (cone 9) is 80°C to 90°C, or a difference of 4 to 4½ cones. For the purpose of comparison the iso-deformation temperature lines are plotted on the field of porcelain glazes burned at cone 11 and

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previously reported,[1] Figure 3. The high gloss axis QT lies to the right of the glaze-SiO_2 eutectic axis and crosses the glaze-Al_2O_3 eutectic axis close to the eutectic member of the group. The best glazes in this group are found in close proximity to the group eutectic, the same as in the cone 9 burn. Not only does the group eutectic lie near the center of the area of best glazes, but it is also located at a safe distance away from devitrification, crazing, matness and immaturity.

Ceramic Laboratories,
University of Illinois.

[1] Influences of variable Silica and Alumina on Porcelain Glazes of Constant RO, *Trans. Amer. Cer. Soc.*, Vol. xiv, pp. 62-70.

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NOTES ON THE COOLING OF VITRIFIED PIPE

BY S. C. KARZEN

The following article represents a few experiments and observations upon the cooling of vitrified sewer pipe which the writer has made at different places and times under different weather conditions, and from clays which produced bodies of radically different nature, as to density and liability to cracking.

At one of our factories, manufacturing vitrified shale sewer pipe, considerable trouble was encountered in the cooling after burning. Pipe would check in kilns which were comparatively new, and under conditions which were favorable for safe cooling. Some scheme had to be devised, by which the cooling could be done rapidly and safely. With this object in view, a number of letters were sent to different members of our society, actively engaged in the manufacture of sewer pipe, asking for any data on cooling which they might be in position to give. I must admit that my inquiries brought very little results, most of the evidence obtained was of a contradictory nature. Whether it was a case of secrecy, or simply that very little was known about the subject, is more than I can say. Several suggested methods would have required the constant attention of a ceramic chemist in a plant of our size. I desired a simple, concise method, which could be handled by men of low intelligence, and which required no attention after the kiln was launched in its cooling.

In order to fully understand the final changes made, a short description of the old method of cooling will not come amiss. I give here the system formerly used in cooling 24 in. double strength pipe. which was the largest pipe made and the most difficult to cool. The kiln was allowed to draw up the stack for about 18 hours after being salted. Then the damper was dropped, and the stack draft shut off completely. The "back draft" plate was drawn back about six inches, and the cold air allowed to rush in through the stack flue. The fire holes are open, and reheating takes place as the heated air from the kiln passes over

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them. The kiln would stand thus for several hours. Then the fire holes were ashed up tightly, and a small hole made in the kiln door to allow the heat to escape. On the morning of the third day, the kiln was considered cool enough to be tapped. By tapping I men tearing down the kiln door. The tapping was done slowly, a course of brick every hour or so, the door being completely down in 24 hours. On the morning of the fourth day, the fire holes were cleaned out; in the afternoon, the crown covers were removed, and the damper drawn that evening. On the morning of the fifth day, the kiln was ready to draw.

As you will note, from the morning of the third day, when the door was tapped, ample precautions were taken to ensure safe cooling. Hence the point at which the air checking took place was between the time when the kiln was finished and the time the door was tapped. After much thought on the subject, I set up the following conditions which an ideal cooling system had to meet to give results.

First. Prevent sudden changes in the kiln atmosphere after the kiln has commenced cooling; that is, sudden fluctuations of the draft, sudden cooling and reheating due to any agency.

Second. The cooling must be uniform over the entire kiln. No one section should cool faster than another, all should proceed evenly and uniformly, much in the same way as the original burning had taken place.

Third. Above all things, the system must be simple and fool-proof. By this I mean, that the cooling operation must be done quickly and simply, so that labor of poor quality could handle it easily.

I felt my system simply had to meet these conditions to prove successful. Let us now examine the old method to see how far short it fell of these ideal conditions. As stated, the kiln was allowed to stand for fully eighteen hours without being touched in any way. During this entire period, it was drawing up a continuously cooling stack. As the stack cooled, its suction necessarily decreased, and this in itself would finally lead to counter currents and cross currents of air in the kiln. Moreover, the fact that the fire holes were allowed to be exposed for

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so long a period laid the kiln open to wind and sudden climatic changes which often prove disastrous. The draft is reversed at a late period in the cooling, when the kiln is becoming especially sensitive to sudden changes. The fire arches commence to reheat, as do the bottom pipe in the kiln, and this would surely prove dangerous to sensitive ware. Finally and worst of all, after the fire holes are closed, we attempt to remove the heated air at a small opening in the door. It is obvious that uniform cooling cannot be obtained by attempting to remove the heat at one small opening. The ware near the door would cool very rapidly, while that farther in the kiln would remain hot for a long period. When the door was tapped, cooling would proceed more rapidly, and this still hot ware would check.

The system in use evidently violated every condition which I considered as necessary for good cooling. I decided, therefore, to make the following changes:

First. Drop the damper and cut off the draft as soon after the salting as feasible. A certain amount of burning fuel remains after the salting is complete, which prevents immediate reversal of the draft, as the products of combustion will reduce and discolor the ware, unless we allow the fuel to burn up completely. For this, I found that about two hours was enough.

Second. Make the back draft opening about 6 in. by 24 in. This is merely a nominal figure and of no great importance, as I will point out later.

Third. Immediately on reversing the draft, close the fire holes tightly, either ashing or mudding them. Under such conditions, the kiln is perfectly tight.

Fourth. Remove the heat through the crown holes. Cooling holes should be cut in the crown, about 8 in. square, placed at a point directly between the bags. Covers should be provided for these, as well as for the center crown hole. By moving these covers, we can remove the heat at any rate of speed.

Considerable experimental work was necessary to determine just the right sized opening to obtain the best results. If the openings were made too large, the ware would cool too rapidly, and consequently air check. If, on the other hand, the openings

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be made too small, the ware would not cool rapidly enough, would be hot when tapped, and hence become checked. Smaller ware could be cooled more rapidly than the larger sizes, and a considerable amount of experimental work was necessary, before I finally arrived at the proper sized openings required. Table I gives the method complete, with the size of openings in use at one of our factories in Ohio. At one of our other plants these openings were made considerably larger, and in general the size is determined by local conditions.

TABLE I—COOLING SYSTEM

DIAM. PIPE INCHES	UNTIL DAMPER DROPPED HOURS	UNTIL FIRE HOLES CLOSED HOURS	SIZE OF OPENING BACK DRAFT INCHES	SIZE OF OPENING CENTER SIDE CROWN HOLES INCHES	UNTIL DOOR TAPPED HOURS	DOOR DOWN HOURS	KILN READY TO DRAW HOURS
6-12	2	not closed	6 by 24	not opened	24	12	72
12-18	2	2	6 by 24	¾ by 8	48	24	96
18-20	2	2	6 by 24	½ by 8	48	24	96
20-22-24	2	2	6 by 24	¼ by 8	72	24	120

The points in favor of the system as outlined are numerous:

By immediate reversal of the draft, we do away with unnecessary air currents and drafts, or rather, cause them to occur at a period when the ware is not sensitive. When the cooling has progressed for some little time, the ware becomes more sensitive to fluctuations of kiln atmosphere and thus air-check more easily.

By closing the fire holes tight, we prevent air checking due to sudden atmosphere and climatic changes. Furthermore, we remove the heat all at one point and prevent leakages at the fire holes.

By cooling from the top of the kiln, we are cooling with nature instead of against it. The heated air rises naturally, and hence we are aided by this pressure in the removal of the heat. Furthermore, the cooling of the air is uniformly distributed by these openings over the entire kiln. The cold air passes in through the stack flue, up through the bottom to the crown, and

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is removed there evenly at a speed to suit the operator. In this way, cooling is controlled and concentrated at one point, giving perfect control. The kiln, tightly closed, can only cool through the crown openings, which are adjusted to suit conditions. The cooling can be accomplished as rapidly or as slowly as desired and is always under complete control.

The system is simple, the entire operation is performed at one time. The kiln is not touched from the time the damper is dropped, until the kiln door is tapped. The method is completely under control at all times, which is of prime importance for satisfactory cooling. Using the cooling method as outlined, good results should be obtained. A few other conditions affect safe cooling, and these must be thoroughly understood.

The Effects of a Dirty Kiln Bottom. Very often, where a plant is operated to the full kiln capacity of the factory, the kilns are allowed to stand from one to three years without having the checker bottom removed and cleaned. As a result, material will accumulate in the feather flues over the holes leading into the main flues, often completely closing many of them. The effect of this is that different parts of the kiln cool at different speeds. Where the holes are open the cooling takes place under normal conditions, where the holes are closed, cooling is retarded, and as a result, hot spots are left in the kiln. When the door is tapped these spots will cool down rapidly and produce air checking.

The use of the cooling system has proven the above statements to my entire satisfaction, and has prolonged the life of a bottom in the following way. Suppose a kiln has been cooled regularly for a period of nine months or so without a sign of air checking. Then the kiln commences to show a few air checked pipes. This would indicate that the bottom was commencing to fill up, and that it was time to cool the kiln a trifle slower. By cutting down the size of the openings the kiln would be cooled a day longer, which will help for a while. The kiln will commence to show signs of air checking again as the bottom becomes more filled up. Smaller ware, which are easier to cool and less likely to check, would now be set in this kiln. If the ware still

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continues to check, no other course remains except the removal of the bottom and a thorough cleaning of the feather flues. Whenever this was done air checking would cease completely, and the largest ware could be cooled safely. This proved conclusively how vital a clean bottom is for efficient cooling. It also shows what nice control the system gives us, and how it helps increase the life of a kiln bottom to a considerable extent.

The Effect of the Type of Flue System. It is reasonable to suppose that a flue system which will give an even distribution of heat in burning will also produce even and uniform cooling. In other words, cooling, a direct antithesis of burning, is more or less subject to the same laws by which flue openings are regulated. Extreme care should be used in the cooling of kilns with old-fashioned flue systems. I cannot speak too strongly against the use of the so-called "ring flue" system. In this system a circular flue is completely around the kiln, next to the walls. From this, one center flue connecting into the ring flue passes to the stack. One small opening leads directly into this stack flue, and is in the center of the kiln. Openings leading into the ring flue are placed between the bags. This is one of the poorest flue systems I have ever encountered, so far as both burning and cooling are concerned. I am using this particular system as an example, because I have found its use prevalent in the sewer pipe districts of Ohio and to a small extent in Michigan.

Cold air is drawn upwards, principally around the outside of the kiln with very little at the center, and this invariably causes unequal cooling and air checked ware. On tearing out this flue system and replacing with the radiating flue system or some similar system, no further trouble was encountered. Too much care cannot be used in the selection of a bottom for kilns, especially in a region where the clay is sensitive in cooling. Any system, by which reasonable heat distribution is obtained in burning, should give good results in cooling.

The Effect of the Back Draft Opening. With the use of the updraft system of cooling, I find that the opening at the stack used to admit the cold air may be of any size. The influx of air

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is controlled by the top covers. The more heated air we release at the crown the greater will be the suction at the back draft plate. It is obvious that we must not choke this opening, as we would thus be working towards a vacuum and be retarding the cooling. But we have nothing to fear from making the opening too large, as the crown covers take care of the supply. Care should be used to keep this opening large enough.

For the information of those who may not know what I mean by back draft opening, I wish to state that the flue at the stack is left exposed directly at the point where it enters the stack. A plate is used to cover this opening, and this of course should be kept tight in burning, as it will check the stack draft otherwise. In cooling, the damper is dropped, and the stack draft is thus cut off. Then the plate just mentioned is drawn back, and cold air is thus admitted into the stack flue and drawn into the kiln. I use an opening 6 in. by 24 in., but it may be made larger if desired, as the amount of air drawn in is regulated by the crown openings.

Cooling, of course, is more or less affected by poor kiln walls, and care should be taken to keep the walls in as good shape as is practical. Strong winds can very readily air check a kiln of ware, if the walls be at all leaky.

Period of Greatest Danger in Cooling. I have found statements by many prominent authorities, leading to the conclusion that the period of greatest danger in cooling is at a time when the ware is just turning from red to black. Acting on this theory, I attempted to open the crown covers more widely the first six hours of cooling and cutting down on the opening, as the so-called danger point was approached. After considerable experimenting, I finally was forced to the conclusion that it was just as dangerous to hurry a kiln at the first part of the cooling as at the latter part. It is also possible to air check a kiln of ware, after the same is perfectly black. It has been my experience, therefore, that no definite danger period can be assumed, and that it is necessary to use a uniform rate of cooling for good results.

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In conclusion, I wish to say that the system I have just outlined is not exactly original with me. I have found it in use to a greater or less extent and in a very haphazard fashion in different factories through the east. However, very few of the burners use the same methods or have a very definite system, the element of chance entering very largely into the operation. I feel confident, however, that the cooling, if handled in the way I have outlined, would be under complete control. I have used it in factories manufacturing ware from both fire clay and shale, and in sections where the clay was highly calcareous, being neither shale nor fire clay, and invariably obtained good results.

DISCUSSION

Mr. Lovejoy: Mr. Karzen's paper brings out some points that interest me very much. We have always held that it was perfectly safe to cool rapidly at the early stage of the cooling, and slowly during the low temperature or so-called danger period, as Mr. Karzen puts it. In wares other than sewer pipe, however, after we get below this, we never consider it any danger. Of course that stage is different in glazed ware; and we may have checking occur months after it comes from the kiln; but in common ware there is no danger after it gets below red. It would be interesting to know whether it is true that it is necessary to cool equally slowly throughout. We have held to the contrary.

Mr. McDougal: This paper recalls something which quite startled a class from the university when some time in 1910, we visited a sewer-pipe plant in Haydensville, Ohio. As we came into the yard we saw kiln men tearing down the door and pulling the fire from a kiln of sewer pipe which had just been burned off at a white heat of about cone 9. As I remember it, water was thrown into the fire boxes both for the purpose of cooling and to make more friable and more easily extricated the clinker that remained. Although the stack damper had been closed, the crown holes were open. After this cooling by radiation to a dull red heat, the door was roughly rebuilt, the crown holes closed and the stack damper partly opened. They claim that they had

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no trouble with air-checking so long as the usual precautions were observed after the dull red stage had been reached.

Mr. Lovejoy: We have the practice of the National Sewer-Pipe Company. What is the practice of the American?

Mr. Karzen: Mr. Lovejoy errs when he considers either Mr. McDougal's version or mine as a particular of any one company. It depends entirely upon the nature of the clay. The clay that Mr. McDougal refers to is a No. 2 fire clay in use by the National Fireproofing Co. A clay of this type is a safe cooling proposition, and it would be a very difficult matter to air-check the same. Our company has several factories manufacturing ware from No. 2 fire clay, and they never have any trouble in cooling and consequently use no particular method. Where we use shale as the basis of our mix we have quite a different proposition. Hence some definite scheme must be used to cool the ware safely. I hope that no one will consider this article as the practice of a certain company. The nature of the clay itself must determine the method of handling. A perfectly safe cooling clay needs no particular method.

Mr. A. F. Greaves-Walker: I want to ask Mr. Karzen how the American Sewer Pipe Company finds any money in taking an extra day to cool off the kiln because they do not want to take the trouble to clean the bottom? Why do they not put in bottoms that do not require absolute tearing out or any tearing out and that can be cleaned for two or three dollars at a time. In most plants the trouble is in shortage of kiln capacity. If you take a day longer to cool each kiln you reduce the capacity of the plant, and most people know that capacity means dividends.

Mr. Karzen: The reason for not tearing out a bottom would be because we did not want to lay the kiln off. You have a regular cycle in setting ware. When it comes to the turn of the one doing the air-checking, it necessitates laying the kiln off three weeks, whereas the extra day we give to cooling that one kiln hardly affects the production at all. On the other hand, the two weeks laying off to put in the new bottom is a serious proposition when running to kiln capacity. As to cleaning without tearing

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the complete bottom out, it is impossible, you have to tear the bottom out completely.

Mr. Greaves-Walker: I want to say to Mr. Karzen that I have had sewer pipe kilns that could be cleaned at any time for two or three dollars without touching the bottom. The dirt could be gotten out without doing so. Why take two weeks then? If the American Sewer Pipe Company can not do it in less time, it seems to me there is a chance for improvement in their work.

Mr. Lovejoy: Mr. Walker, when the bottom is cleaned so easily is it fully perforated?

Mr. Greaves-Walker: Yes by using a center kiln and having the secondary flues all slope toward the center flue and by having a manhole on the outside where a man could take the refuse from.

Mr. Bowman: I should like to ask where the air-checking takes place mostly; at the top or at the bottom?

Mr. Karzen: At the bottom. The ware with which we have most of the trouble is the bottom pipe. I have seen kilns that were checked from top to bottom, but it is not the usual thing.

Mr. Bowman: I noticed in the description of the cooling that you plastered up the kiln and put down the damper and opened up the top of the kiln, cooling from the top. Why did you put down the damper? If you closed up the fire holes you could not have any draft from them and by letting the heat out of the stack and opening up the top stacks you might induce the draft to go down through the kiln and hold the bottom temperature near to that of the top and in that way prevent dunting. That was the experience I had twenty-five years ago in cooling from an opening in the top of the kiln. We had an opening in the center of the crown of the kiln of about 18 inches, and as soon as the kiln was fired off we waited for a few hours (I do not know exactly how long) until the fuel in the fire holes burned out, then we opened the hole in the top of the kiln, but did not close the damper to the main stack of the kiln, but permitted the heat to go out that way. We never experienced dunting, but this

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may have been due to the fact that our pipes were made of a fire clay body.

Mr. Karzen: May I ask how long it took to cool off?

Mr. Bowman: I think we used to take three days to cool off.

Mr. Karzen: It is necessary to drop the damper as I have already pointed out, a continuously cooling stack means a continually decreasing suction and consequently will eventually lead to fluctuating air currents in the kiln atmosphere. With a safe cooling clay this will have no effect. With a tender clay it will invariably lead to air-checked ware. The heat must be removed at one point to give perfect control.

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A STUDY OF THE ATTERBERG PLASTICITY METHOD[1]

BY C. S. KINNISON, PITTSBURG, PA.

A method for measuring plasticity is described by Albert Atterberg,[2] which is based upon the varying physical behavior of clays with different water contents. As we add water in increasing amounts to a clay powder, says Atterberg, the clay assumes first a condition where it can be made to hold together by pressure, then the state where it possesses its best working qualities, passing into a sticky condition, and finally is as a thin, watery fluid with an excess of water. The various clays assume any one of these conditions within varying limits of water content. For instance, if a clay is very plastic there is a considerable range in the water content within which it remains workable, while one whose plasticity is feeble permits only of a narrow range in its water content. If we determine the limits of the water content, according to Atterberg, at which the various clays pass from one condition to another, we have a valuation of their relative plasticities.

Atterberg classifies the condition of a clay with varying amounts of water into five different states as follows:

1. The upper limit of fluidity, or the point where the clay slip flows as water.

2. The lower limit of fluidity, or flow, the "*fliess-grenze,*" where two portions of the clay mass can be made to barely flow together when placed in a shallow dish and sharply rapped with the hand.

3. The normal consistency or "*klebe-grenze,*" the condition in which the clay is most workable, is no longer sticky and will not adhere to metal.

4. The "*ausroll-grenze,*" or rolling limit, the point at which the clay can no longer be rolled into so-called threads, between the hands and the surface on which it may rest. This is the lower limit of the workable condition.

[1] By permission of the Director of the Bureau of Standards.
[2] *International Reports on Pedology,* 1911.

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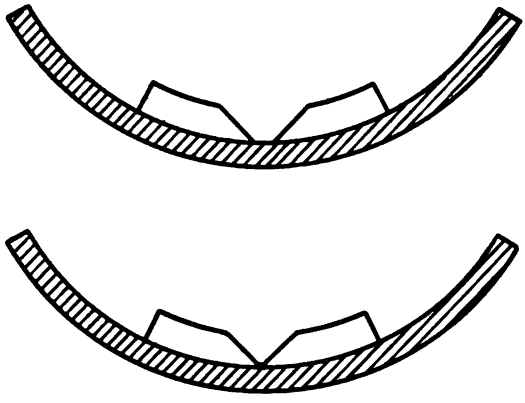
5. The point at which the damp clay will no longer hold together when subjected to pressure.

According to this classification, it is apparent that the workable stage is limited by the boundaries of condition No. 1 and condition No. 2, or in other words, a clay is workable between the point where it will barely flow (where this point is determined by the method mentioned above) and the point at which it can no longer be rolled into threads. It is Atterberg's contention that the wider this range the more plastic is the clay. It is clear that the establishment, or fixing of these points is arbitrary. The method adopted by Atterberg is as follows:

TRANS. AM. CER. SOC. VOL. XVI KINNISON
FIG. 1.



The Flow-limit, or Fliess-grenze. About five grams of the clay powder, of approximately 120 mesh, are put into a small porcelain evaporating dish and made to a paste by the addition of distilled water. By means of a polished nickel spatula, the mass is shaped into a smooth layer, a trifle less than 1 cm. (.39 in.) in thickness. The clay is then divided into two portions by cutting a triangular shaped channel through it, as shown by Fig. 1, the lower edges being separated a trifle.

The dish is then repeatedly and sharply rapped against the heel of the hand in order to bring about the flowing together of the mass. The limit has been reached when the two portions of

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the clay barely meet at the bottom, thus as shown by Fig. I. If the paste is too thick, or too thin, water or clay is added until the proper consistency has been attained.

The water content at this consistency is then carefully determined by drying to constant weight and is expressed in terms of percent of the dry weight of clay.

The Lower Plasticity Limit, or Ausroll-grenze. Clay in the stiff plastic condition is rolled on paper to form "threads" of clay. These are broken, put together and again rolled out. It does not matter if the threads break up into smaller lengths. Clay powder is then added to the mass and thoroughly worked and again rolled into threads. The limit has been reached when the threads crumble down. The water content is determined at this point and expressed in terms of percent of dry weight of clay. This figure subtracted from the one determined above is called the "plasticity number," and the higher its value the more plastic is the clay.

In this connection a revised adaptation of a method originated by Bischoff was used in which the clay is mixed with varying amounts of sand of different fineness, 0.2 to 0.06 m.m., and the effect of such additions on the plasticity studied. Atterberg's method consisted in adding to the clay powder fine sand, in the ratio of clay to sand as 1:0.5, 1:1 and 1:2. The flow limit, the sticky limit, or "*klebe-grenze,*" and the "*ausroll-grenze,*" or the point where the clay can no longer be rolled into threads, were then determined in these three mixtures. If the mass, at the flow limit, could not be rolled into threads, it was considered as non-plastic. Those clays which could be mixed with two parts of sand without losing their plasticity were considered as belonging to the first class, those which could carry only an equal part of sand were put into the second class, while those which, upon an addition of half their weight of, or practically no sand, lost their plasticity, were classed third. The results of this experiment showed that the shape of the sand grains was of much more influence than was their size.

These experiments on nineteen different clays showed that: If a clay, with a lower water content at the normal consistency

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than at the flow limit, be mixed with much sand, the relative position of the water content at the condition of normal consistency is always raised, in reference to the flow limit, and in some cases, rises above it, which shows that the condition of normal consistency cannot be considered as the upper-plasticity limit. In these cases, however, where the water content at the normal consistency lies above that at the flow-limit, then the latter must be considered as the upper limit of plasticity.

Figure 2 illustrating type curves will show more clearly the relations between the flow-limit and the condition of normal consistency, for the clays of the different plasticities.

The diagram shows that these three conditions stand in the following relations to each other: The flow-limit and the rolling-limit coincide in the case of the loams, which Atterberg classifies as non-plastic, but in the case of the clays, they separate more and more as the plasticity increases. These two limits must therefore be considered as bounding the consistencies within which the clay is plastic.

The curve showing the condition of normal consistency or "*klebe-grenze*" follows a decidedly different course, however. In the case of the loams, or "non-plastics," and the clays rich in humus, this limit lies much higher than that of the flow limit.

In the clays low in, or free from humus, the relative position of the flow limit is higher. In the class of highest plasticity, the condition of normal consistency always takes a place below that of the flow limit and approaches more and more the rolling limit, practically coinciding in the clays of highest plasticity.

The condition of normal consistency or the point where the clay is no longer sticky can not, therefore, be considered the upper limit of plasticity. The flow-limit, rather, must form the upper boundary line of the plastic condition.

It is interesting to note, that the condition of normal consistency and the flow-limit approach each other in the less plastic clays, coinciding in the second class, from which point they diverge.

Since, however, the condition of normal consistency in the case of the clays of the first class, falls between the flow limit and

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the rolling limit, two types of plasticity must be recognized, viz., the condition of sticky plasticity and that of the non-sticky. The failure to appreciate this distinction has been the cause of failure of so many of the methods of determining plasticity, says Atterberg.

Although the condition of normal consistency often lies outside the field of the true plastic condition, it still lies within the plastic area in the case of the most plastic clays, in which cases it forms the boundary line between the conditions of sticky and non-sticky plasticity.

Experiments were made on about 25 different clays, with and without sand, representing the four classes of plasticity, to determine the flow limit, the point of normal consistency, and the rolling limit.

The water content at the condition of normal consistency in the clays of the first plasticity class is always lower than that of the flow limit, while in the clays belonging to the third class and in the loams, the water content at this consistency is always higher than at the flow limit. In the clays mixed with sand, the water content at the condition of normal consistency was always higher or in the neighborhood of that at the flow limit. A clay showing a lower water content at the condition of normal consistency than at the flow limit is rather difficult to work. The addition of rather large quantities of fine sand or small quantities of organic material will raise the relative position of this point in reference to the flow limit, and therefore makes them more workable.

The Atterberg method, while perhaps not so well known in America, is being used to some extent in Germany for classifying the clays according to their plasticity. The method is practically as simple a one as could be devised, and if it represents facts, it is well that we should become familiar with it.

To compare it with some of our methods for measuring plasticity, twenty different clays were selected, and their water of plasticity and volume shrinkage determined, as well as the amount of water which the dry powders would absorb when allowed to stand over a dilute sulphuric acid solution, a method

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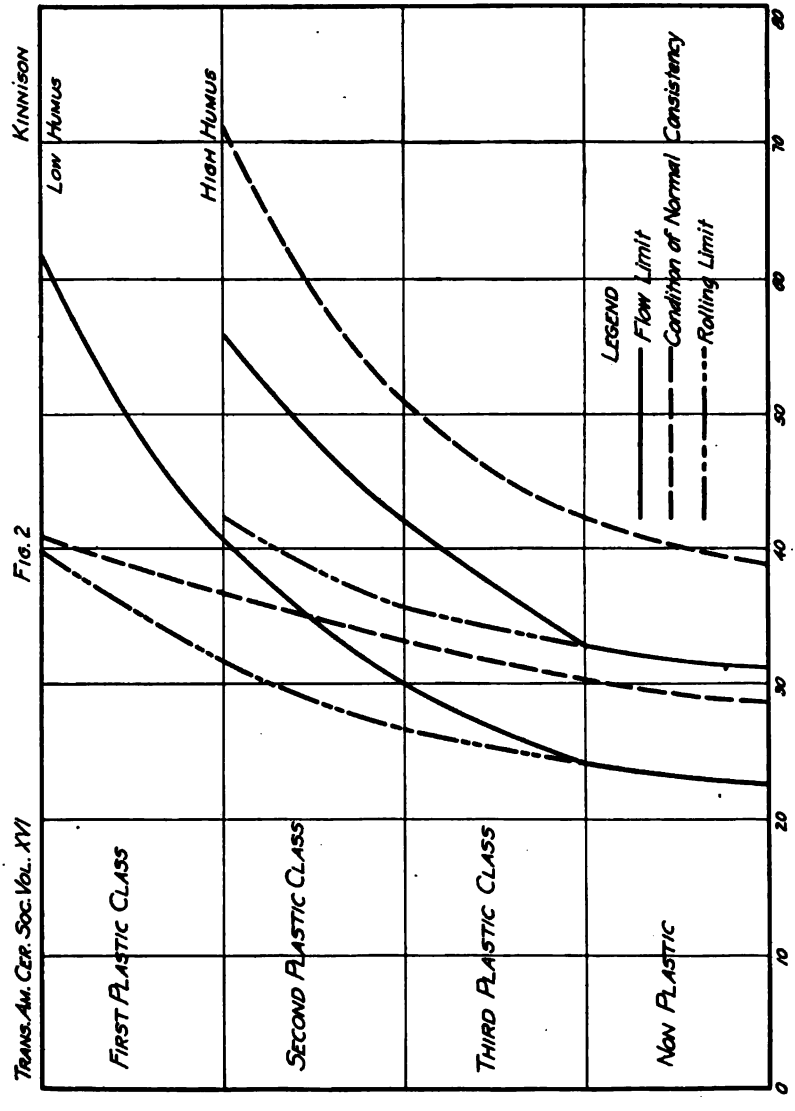

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recommended by Keppler. It is not to be expected that the clays would be classified in the same order by all three of these methods, but from the combined results of these tests, we should be able to classify them rather accurately according to their relative plasticities, inasmuch as they are all directly related to this property of the clay.

The clays used were as follows:

TABLE I

1 Bedford shale
2 G. A. Murray shale
3 McKeehan shale
4 Metropolitan shale
5 Deckman-Duty shale
6 Galesburg shale
7 Kittanning fire clay
8 Union Furnace fire clay
9 Chicago Retort and Fireclay Co.
10 M. and M. ball, No. 11
11 Tennessee ball clay, No. 3
12 Great Beam ball clay
13 Whitaway ball clay
14 M. W. M. china clay
15 M. G. R. No. 2 china clay
16 Ault. No. 3 fire clay
17 Georgia kaolin
18 North Carolina kaolin
19 Texas white clay, 340
20 Florida kaolin

In determining the volume shrinkage each clay was worked to its best consistency, which corresponds to the "*klebe-grenze*" in Atterberg's work. This condition was merely judged by feel. The clays were then put into a humidor and allowed to stand over night when they were removed, and small cylindrical pieces of about 50 cc. contents made for determining the volume shrinkage, the volume measurements being made in kerosene. The water of plasticity was also determined.

These pieces were dried by a method similar to that recommended by Kerr and Montgomery, viz., air drying for about five days, then drying to constant weight at 75° and finally taken to complete dryness at 110°C. The pieces were then dipped in paraffine and their volume determined. Column A of Table II shows the results:

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TABLE II—DATA

CLAY	A SHRINKAGE	B WATER PLAST.	WATER ABSORBED	FLOW LIMIT	ROLLING LIMIT	D PLASTICITY NO.
1	21.7	21.7	5.21	29.8	18.3	11.5
2	23.9	21.9	3.34	28.4	18.7	9.7
3	15.7	17.6	2.20	24.6	16.4	8.2
4	15.0	20.6	3.33	28.9	20.2	8.7
5	15.5	20.0	4.27	27.6	20.7	6.9
16	21.5	18.6	4.79	25.6	15.8	9.8
7	18.8	17.1	3.20	24.3	14.9	9.4
8	20.9	20.8	3.82	27.0	17.6	9.4
17	18.5	25.5	4.71	39.3	26.2	13.1
18	18.8	27.4	4.75	36.1	29.5	6.6
6	17.2	21.1	2.43	27.0	20.0	7.0
9	16.4	15.3	4.90	21.3	13.0	8.3
10	32.5	33.0	10.50	54.7	27.1	27.6
11	35.3	34.4	10.30	50.0	30.4	19.6
12	26.0	31.2	7.84	41.2	29.8	11.4
13	25.9	30.5	7.22	43.9	26.3	17.6
14	21.3	30.6	2.19	40.5	32.7	7.8
15	20.0	30.2	2.51	39.1	31.7	7.4
19	45.0	39.3	20.90	75.4	35.1	40.3
20	24.3	31.1	5.68	45.5	29.8	15.7

For determining the water absorbed the specimens were subjected to the vapor tension of a 10 percent H_2SO_4 solution. About two grams of each clay were accurately weighed in small tin capsules, after having been taken to dryness at 110°. These were then put into a desiccator containing the acid solution; weighings were then made at the end of seven and fourteen days, and then about every two days until practically constant weight was attained. It can be readily seen that changes in temperatures will affect the weight of the clays inasmuch as the vapor pressure of the solution changes with the temperature. In case of a fall in temperature there results a loss in weight due, of course, to the evaporation of the water from the samples. This is only noticeable when the clays practically reach their maximum

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weight, because, as this point is approached, their rate of increase in weight is very slow.

For carrying on Atterberg's test, the clays were thoroughly mixed and screened through 80 mesh, and the method recommended by him followed as accurately as possible. However, instead of using a shallow evaporating dish for determining the flow limit, a flat vitrified porcelain disc was substituted, because when the former was used, there seemed to be a tendency for the clay mass to slide, instead of to flow. This trouble was eliminated by the use of the flat disc. Atterberg does not specify the width which shall separate the two portions of clays, but in our case this distance was made about 1/8 in. Nothing is definitely stated concerning the vigor or number of blows which shall be given to bring about the flow, and, of course, the more vigorous and frequent are these blows, the lower will be the flow limit. In our work the disc was sharply rapped 25 times against the heel of the hand, care being taken to make the impacts of as near the same intensity as possible. Of course, these could not be made exactly equal in each case, and thus constitutes one source of error. We would suggest that a mechanical device of some sort such as a vibrator be used for this determination. It seems furthermore that these impacts should be made against some rigid object instead of the hand. This method classifies the clays as shown in column (D), the most plastic clay being given last position or position No. 20.

It will be noticed from this classification that in several instances the plasticity numbers practically or entirely coincide. According to Atterberg these clays are of practically the same plasticity. The plasticity number obtained merely by difference does not show the location of the clay in its own particular class. For instance, the plasticity numbers of clays, No. 7 and No. 8, coincide; it will be noticed, however, that the water contents do not agree, the difference being approximately three percent. Clays No. 1 and No. 12 also agree very closely in their plasticity numbers, and yet have a difference of 11 percent in their water content. See Fig. 3. As seen in Table I, clay No. 1 is the Bedford shale and No. 12 Great Beam ball clay. They are both very

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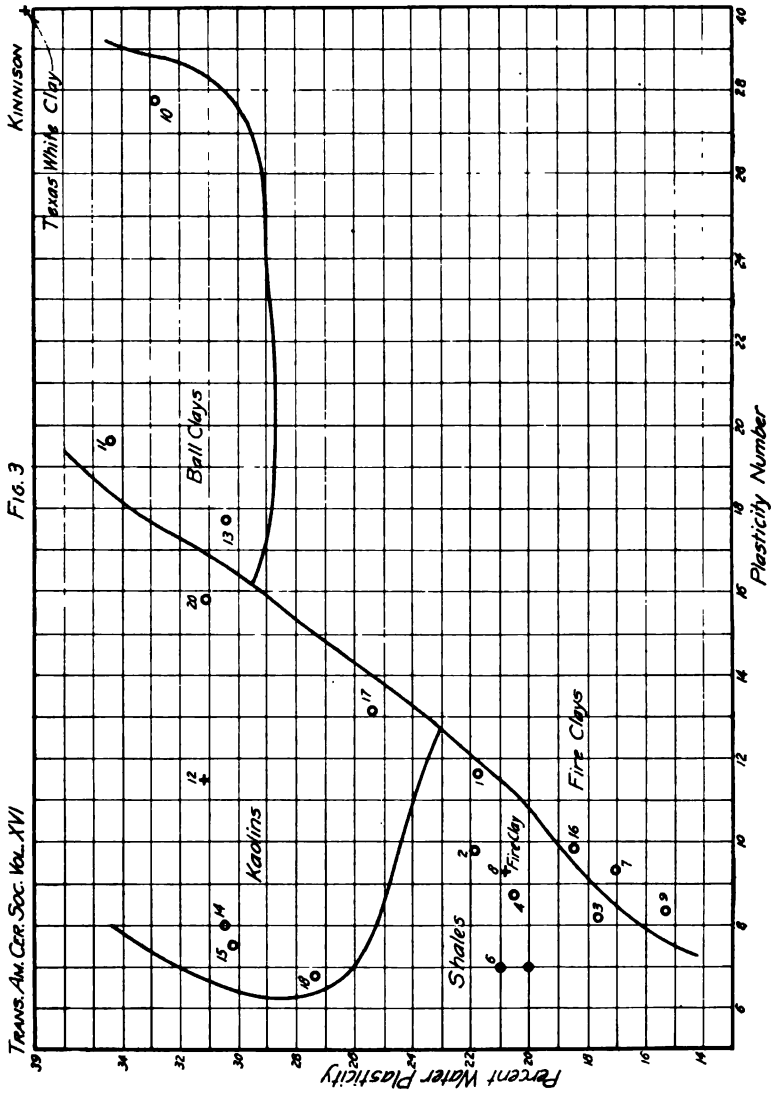

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plastic, but we know, of course, that the ball clay is much more so, but yet has a slightly smaller plasticity number. Now, the plasticity number, as determined by Atterberg, does not take into account this consideration, just mentioned. It seems logical that a clay having the higher water of plasticity content and yet the same plasticity number as some other clay, would be more plastic than the latter. The facts would be more clearly represented if these numbers were multiplied by some factor, to take into account this difference in water content. For instance, multiply by the percent water of plasticity. Such a procedure gives the classification, in column marked (BxD), Table III.

TABLE III—CLASSIFICATION BY ALL METHODS USED

CLAY NO.	A x B	A SHRINKAGE	B WATER PLAST.	ATTERBERG	BxD	C VAPOR ABS.	AV.	OFF ATT.	OFF AxB	OFF C	OFF BxD	OFF B	OFF A
1	9	13	9	14	14	14	12	2	3	2	2	3	1
2	12	14	10	11	12	7	11	0	1	4	1	1	3
3	2	3	3	6	4	2	3	3	1	1	1	0	0
4	3	1	6	8	5	6	5	3	2	1	0	1	4
5	4	2	5	2	1	9	4	2	0	5	3	1	2
6	6	5	8	3	2	3	5	2	1	2	3	3	0
7	5	7	2	9	9	5	6	3	1	1	3	4	1
8	8	10	7	10	10	8	9	1	1	1	1	2	1
9	1	4	1	7	6	13	5+	2	4	8	1	4	1
10	18	18	19	19	19	19	19	0	1	0	0	0	1
11	19	19	18	18	18	18	18	0	1	0	0	0	1
12	15	17	17	13	15	17	16—	3	1	1	1	1	1
13	16	16	14	17	17	16	16	1	0	0	1	2	0
14	14	11	15	5	8	1	9	4	5	8	1	6	2
15	13	9	13	4	7	4	8	4	5	4	1	5	1
16	7	12	4	12	11	12	10	2	3	2	1	6	2
17	10	6	11	15	13	10	11	4	1	1	2	0	5
18	11	8	12	1	3	11	8	7	3	3	5	4	0
19	20	20	20	20	20	20	20	0	0	0	0	0	0
20	17	15	16	16	16	15	16	0	1	1	0	0	1
								—	—	—	—	—	—
								43	35	45	27	43	27

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Arranged in the inverse order of their gain in weight when subjected to a vapor tension, the clays are classified as shown in column (C).

It will be noticed that this order checks quite closely with that given in column marked (AxB). There are, however, three cases where the arrangement is widely different, viz., in clays Nos. 9, 14, 15. The first of these clays is that of the Chicago Retort and Fire Clay Co., and has excellent working properties, yet column (AxB) classifies it as the poorest of the lot. Clays No. 14 and No. 15 are both china clays whose working qualities are only fair, yet they are ranked with the most plastic by column AxB, and given decided preference in position over clay No. 9. Our common everyday experience with these clays would undoubtedly make their arrangement as given under column (C) seem the more nearly to represent the facts.

In determining the amount of water absorbed, we do not agree with Keppler, however, in recommending that the samples be under a vacuum at the same time. A vacuum should at first be produced to remove the air, but should not be maintained. The vacuum will gradually fall, of course, due to the evaporation of the water.

If the vacuum be maintained the vapor pressure is lowered so much that the operation is much too slow, and also makes the results inaccurate. When the samples were weighed at the end of the 15th day, after being subjected to the vacuum continuously, they were found to have attained a practically constant weight. When put back into the humidor, however, the suction cut off, they gained rapidly, the rate of increase being more than three times that when the vacuum was used. The order, based on the gain in weight when in the vacuum, scarcely agrees in any way with those given by any of the other methods used.

In an attempt to draw conclusions as to which of the methods used most nearly represented the facts, the "average position number" was determined, as shown in column marked "Av." The difference between this value and those given for that clay by the other methods was determined, and the figures so obtained

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arranged in the columns as shown, which show how far off the average position are those given by the methods used.

It is interesting to note in this connection that the total points off the average, as shown by column AxB is exactly the average of the variance from the average, as shown by columns A and B. It is also seen that the order as given under column BxD is nearer to the average than either arrangement under B or D.

These figures have no particular significance other than to show that the Atterberg method is no improvement over any of our own, and that the old method of classification based on the percent volume shrinkage is about as satisfactory as any that we now have.

None of the methods seem to exactly show the facts as we judge them from experience. However, a classification based on all of these methods should reveal the facts fairly accurately, but no one method with which we are now familiar will suffice.

Arranged according to AxB, the Chicago Retort and Fire Clay Co. clay is the least plastic, but such is not the case. North Carolina kaolin is ranked among the best by this method, while as a matter of fact it is the least plastic of the lot, and Atterberg's method places it where it belongs. Similar misrepresentations could be shown for all the methods employed, and none has any decided advantage.

In conclusion, Atterberg's method itself is open to one sharp criticism, namely: that the plasticity number does not locate the clays in their respective classes. We might say it is analagous to two equations with three unknowns. Thus, for instance, the Bedford shale is classed along with the Great Beam ball clay.

In order to correlate the Atterberg valuation with the actual character of the clay it is suggested that a diagram be used as shown in Fig. 3. Here the Atterberg plasticity number is coordinated with the water of plasticity.

DISCUSSION

Mr. Watts: I have been very much interested in this paper, especially because of the fact that we have been endeavoring to make some physical measurements of clays at the

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Ohio State University, and the problem of measuring plasticity has come in for its share of attention. We had only the data that, up to the present time, have been available along this line, and felt rather helpless in devising schemes for measuring plasticity, but we finally hit upon a combination of tests which includes the following:

The first test was the knife test; that is to say, the wedging of clay until it became plastic, adding water at frequent intervals and in small amounts. In order to determine the exact point, we took a small, sharp spatula of the regular four-inch size and, having the blade smooth and sharp, cut a slash through the molded clay. After doing this, we pressed the blade of the knife flat on one side of the cut, to determine whether or not there was any evidence of healing. We took the point where the clay united as one of our end points. We found that twelve of the clays which we tested in that way checked up in rather fair order. For the second point, we used a No. 12 nickeled brass wire loop, ½ cm. in diameter. These loops were carefully made; and we continued to add water to the clay, which now became slip, until by having a depth of about half an inch of this plastic clay, and passing the loop along the bottom of this clay mass and drawing it up through the clay, we just retained a globule of clay in the loop. The addition of one-half of one percent of water resulted in the refusal of the loop to retain a globule of clay. Water was then added until we obtained a slip that would again adhere as a globule on the loop. This, you will understand, was a very thin slip, and was approaching the watery or milky stage only. That gave us three points which we could correlate, and we found some rather interesting results in the preliminary investigation. I do not know how successful we shall be in this, because the major portion of the work is being done by students, who are now juniors, and the personal factor, of course, comes in, but we are very much in hopes of getting some data which we shall be able to correlate. We see every evidence of the clays lining up by this system of tests into about the same classification as they would be normally placed by the average potter who depends simply on his judgment and his ac-

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quaintance with the various clays in deciding the order into which they should fall.

Mr. Back: I should like to ask Mr. Kinnison what drying treatment he gave the clay samples which were used in the absorption test in which sulphuric acid was employed.

Mr. Kinnison: I merely took them to constant weight at 110°.

Mr. Back: How heavy are the samples when dry?

Mr. Kinnison: About two grams.

Mr. Back: How do you account for the fact that when you removed the vacuum and put the samples back, you find increased absorption?

Mr. Kinnison: Evidently the increased absorption is due to the increased amount of vapor.

Mr. Back: Was your vacuum always the same during the absorption treatment of the several samples?

Mr. Kinnison: Practically so; they were all subjected to the same treatment.

Mr. Back: I asked this question because in this absorption test, which is practically the Rodenwald-Mitscherlich hygroscopicity test, this drying treatment would not apply to humus soils because the humus would be so affected as to give a lower absorption value for the soil than it actually has. Possibly a similar error is introduced when working with clays and clayey soils if such a drying treatment is used. It might be better to accomplish the drying by desiccating with P_2O_5 for example, and eliminate the application of heat.

Mr. Kinnison: The only point is to obtain some figures on which to base the increase in weight.

Mr. Back: If the drying treatment is the same for all samples, it may be alright as far as obtaining samples of equal weight is concerned; but not so for the absorption results which are determined, because any effect, which organic matter might have, would be altered and possibly eliminated under such heat treatment.

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THE PRODUCTION OF UNDERGLAZE COLORS BY THE USE OF SOLUBLE METALLIC SALTS[1]

BY R. M. HOWE, ALFRED, N. Y.

OBJECT OF INVESTIGATION

Becoming interested in the results obtained by Dr. Pukall and later ones by Dr. Buttner, in the production of underglaze colors by the soluble salt method, I decided to work along similar but more extended lines, for the benefit of those members of the society who are not able to take advantage of German technical literature. It was hoped, in this investigation, to secure a great variety of colors, and to study the influence of the different refractory bases upon the color produced by the metallic salt.

OUTLINE OF THE WORK

Materials Used. The metallic salts used in the production of these colors were commercial ones, though of a high degree of purity, so that the reproduction of the colors obtained is well within the scope of the manufacturer. Those used were as follows:

$Co(NO_3)_2$ $6H_2O$
$UO_2(NO_3)_2$ $6H_2O$
$FeSO_4$ $7H_2O$
Cr_2Cl_6
$MnSO_4$ $4H_2O$
$Ni(NO_3)_2$ $6H_2O$

The bases were of commercial standard and were ground in a ball mill for two hours. The last base mentioned is expressed in terms of equivalents. Those used were:

Aluminum hydrate ..... $Al_2O_3.3H_2O$
Kaolin ..... $Al_2O_3.2SiO_2.2H_2O$
Silica ..... SiO_2
Calcium phosphate (bone ash).... $Ca_3(PO_4)_2$
1.0 Aluminum hydrate ..... $Al_2O_3.3H_2O$
0.5 Zinc oxide ..... ZnO

[1] A contribution from the laboratories of the New York State School of Clay Working and Ceramics under the direction of A. R. Heubach.

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Methods of Preparation. The first step in the preparation of each color body was to weigh out the equivalent weight of the metallic salt used, transfer it to a porcelain evaporating dish and dissolve it in distilled water. One equivalent of the base used for that body was then introduced into the solution. The mixture was brought to dryness over a water bath, constantly stirred in the meantime with a glass rod. By this method, not only the finest conceivable division of the metallic salt was secured, but also a very uniform mixture.

These dry mixtures were placed in a white-ware biscuit crucible and subjected to the calcining temperature, indicated in the table giving the compositions of the color bodies.

Composition of the Color Bodies. Table I shows the proportion in which the raw materials were mixed. The color of each color body after calcining is indicated that it may be contrasted with the color secured under the glaze.

Preparation of the Trials. The colors were ground by hand upon a glass plate. Ten percent of ball clay, glycerine and a little water was added to each, the first being used merely to serve as a bond. The colors were then applied with a brush in the customary manner, in thickness of one, two, three and four layers so that the influence of the thickness of the color, if any, could be observed. In the first sets of trials, the underglaze colors were applied to cylindrical biscuited pieces, each one providing sufficient space for twenty-four colors. The trials were then fired to about 600°C. for the purpose of volatilizing the organic matter and to make the colors firm enough for dipping.

Bodies and Glazes Used:

Earthen-ware Body. Biscuited at Cone 7

English ball clay	98.5
Tennessee ball clay No. 1	98.5
Kaolin	297.5
Eureka spar	34.0
Flint	471.5
	1000.0

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TABLE I

NO.	BASE	WEIGHT	METALLIC SALT	EQUIVALENT	WEIGHT	CALCINING HEAT	COLOR
A1	$Al_2O_3 . 3H_2O$	156.0	$Co(NO_3)_2\ 6H_2O$	0.05	14.55	7	blue
A2	$Al_2O_3 . 3H_2O$	156.0	$Co(NO_3)_2\ 6H_2O$	0.10	29.10	7	blue
A3	$Al_2O_3 . 3H_2O$	156.0	$Co(NO_3)_2\ 6H_2O$	0.20	58.20	7	blue
A4	$Al_2O_3 . 3H_2O$	156.0	$Co(NO_3)_2\ 6H_2O$	0.50	145.50	7	blue
A5	$Al_2O_3 . 3H_2O$	156.0	$Co(NO_3)_2\ 6H_2O$	0.70	203.70	7	blue
A6	$Al_2O_3 . 3H_2O$	156.0	$Co(NO_3)_2\ 6H_2O$	1.00	291.00	7	blue
B1	0.5 ZnO 1.0 $Al_2O_3 . 3H_2O$	196.5	$Co(NO_3)_2\ 6H_2O$	0.05	14.55	7	blue
B2	0.5 ZnO 1.0 $Al_2O_3 . 3H_2O$	196.5	$Co(NO_3)_2\ 6H_2O$	0.10	29.10	7	blue
B3	0.5 ZnO 1.0 $Al_2O_3 . 3H_2O$	196.5	$Co(NO_3)_2\ 6H_2O$	0.20	58.20	7	blue
B4	0.5 ZnO 1.0 $Al_2O_3 . 3H_2O$	196.5	$Co(NO_3)_2\ 6H_2O$	0.50	145.50	7	blue-green
B5	0.5 ZnO 1.0 $Al_2O_3 . 3H_2O$	196.5	$Co(NO_3)_2\ 6H_2O$	0.70	203.70	7	green-blue
B6	0.5 ZnO 1.0 $Al_2O_3 . 3H_2O$	196.5	$Co(NO_3)_2\ 6H_2O$	1.00	291.00	7	green-blue
C1	SiO_2	60.0	$Co(NO_3)_2\ 6H_2O$	0.05	14.55	7	light purple
C2	SiO_2	60.0	$Co(NO_3)_2\ 6H_2O$	0.10	29.10	7	light purple
C3	SiO_2	60.0	$Co(NO_3)_2\ 6H_2O$	0.20	58.20	7	reddish purple
C4	SiO_2	60.0	$Co(NO_3)_2\ 6H_2O$	0.50	145.50	7	royal purple
C5	SiO_2	60.0	$Co(NO_3)_2\ 6H_2O$	0.70	203.70	7	royal purple
C6	SiO_2	60.0	$Co(NO_3)_2\ 6H_2O$	1.00	291.00	7	royal purple

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TABLE I—Continued.

NO.	BASE	WEIGHT	METALLIC SALT	EQUIVALENT	WEIGHT	CALCINING HEAT	COLOR
E1	$Al_2O_3 . 3H_2O$	156.0	$UO_2(NO_3)_2\ 6H_2O$	0.20	100.60	07	light gray
E2	$Al_2O_3 . 3H_2O$	156.0	$UO_2(NO_3)_2\ 6H_2O$	0.40	201.20	07	light gray
E3	$Al_2O_3 . 3H_2O$	156.0	$UO_2(NO_3)_2\ 6H_2O$	0.75	378.25	07	dark gray
E4	$Al_2O_3 . 3H_2O$	156.0	$UO_2(NO_3)_2\ 6H_2O$	1.00	503.00	07	dark gray
F1	$Al_2O_3 . 2SiO_2 . 2H_2O$	258.0	$UO_2(NO_3)_2\ 6H_2O$	0.20	100.60	07	gray
F2	$Al_2O_3 . 2SiO_2 . 2H_2O$	258.0	$UO_2(NO_3)_2\ 6H_2O$	0.40	201.20	07	gray
F3	$Al_2O_3 . 2SiO_2 . 2H_2O$	258.0	$UO_2(NO_3)_2\ 6H_2O$	0.75	377.25	07	gray
F4	$Al_2O_3 . 2SiO_2 . 2H_2O$	258.0	$UO_2(NO_3)_2\ 6H_2O$	1.00	503.00	07	gray
G1	$Al_2O_3 . 2SiO_2 . 2H_2O$	258.0	$FeSO_4\ 7H_2O$	0.10	27.80	02	orange
G2	$Al_2O_3 . 2SiO_2 . 2H_2O$	258.0	$FeSO_4\ 7H_2O$	0.20	55.60	02	orange
G3	$Al_2O_3 . 2SiO_2 . 2H_2O$	258.0	$FeSO_4\ 7H_2O$	0.50	139.00	02	dark orange
G4	$Al_2O_3 . 2SiO_2 . 2H_2O$	258.0	$FeSO_4\ 7H_2O$	1.00	278.00	02	red orange
H1	$Ca_3(PO_4)_2$	310.0	$FeSO_4\ 7H_2O$	0.20	55.60	02	orange
H2	$Ca_3(PO_4)_2$	310.0	$FeSO_4\ 7H_2O$	0.40	111.20	02	gray
H3	$Ca_3(PO_4)_2$	310.0	$FeSO_4\ 7H_2O$	0.80	222.40	02	gray
I1	$Al_2O_3 . 3H_2O$	156.0	$CrCl_2$	0.10	31.60	7	pink
I2	$Al_2O_3 . 3H_2O$	156.0	$CrCl_2$	0.30	94.80	7	brown
I3	$Al_2O_3 . 3H_2O$	156.0	$CrCl_2$	0.50	158.00	7	gray green
I4	$Al_2O_3 . 3H_2O$	156.0	$CrCl_2$	1.00	316.00	7	light green
K1	0.5 ZnO 1.0 $Al_2O_3 . 3H_2O$	196.5	$CrCl_2$	0.10	31.60	7	salmon pink
K2	0.5 ZnO 1.0 $Al_2O_3 . 3H_2O$	196.5	$CrCl_2$	0.30	94.80	7	gray pink

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K3	0.5 ZnO 1.0 Al_2O_3 . $3H_2O$	196.5	$CrCl_3$	0.50	158.00	7	gray brown
L1	Al_2O_3 . $3H_2O$	156.0	$MnSO_4$ $4H_2O$	0.15	33.45	07	light brown
L2	Al_2O_3 . $3H_2O$	156.0	$MnSO_4$ $4H_2O$	0.20	44.60	07	brown
L3	Al_2O_3 . $3H_2O$	156.0	$MnSO_4$ $4H_2O$	0.40	89.20	07	brown
L4	Al_2O_3 . $3H_2O$	156.0	$MnSO_4$ $4H_2O$	0.75	167.00	07	brown
L5	Al_2O_3 . $3H_2O$	156.0	$MnSO_4$ $4H_2O$	1.00	223.00	07	dark brown
M1	0.5 ZnO 1.0 Al_2O_3 . $3H_2O$	196.5	$Ni(NO_3)_2$ $6H_2O$	0.20	58.00	7	very light blue
M2	0.5 ZnO 1.0 Al_2O_3 . $3H_2O$	196.5	$Ni(NO_3)_2$ $6H_2O$	0.40	116.00	7	light blue
M3	0.5 ZnO 1.0 Al_2O_3 . $3H_2O$	196.5	$Ni(NO_3)_2$ $6H_2O$	0.75	218.00	7	blue green
M4	0.5 ZnO 1.0 Al_2O_3 . $3H_2O$	196.5	$Ni(NO_3)_2$ $6H_2O$	1.00	290.00	7	light green

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Glaze for Earthen-ware Body. Fired at Cone 07

$$\left.\begin{array}{l} PbO\ 0.55 \\ BaO\ 0.10 \\ CaO\ 0.15 \\ MgO\ 0.10 \\ K_2O\ 0.10 \end{array}\right| \left.\begin{array}{l} Al_2O_3\ 0.25 \\ B_2O_3\ 0.40 \end{array}\right\} SiO_2\ 2.5$$

This glaze was entirely fritted except 0.15 clay.

Stoneware Body. Biscuited at Cone 07

Cutter's sagger clay	400.0
Eureka spar	210.0
Flint	390.0
	1000.0

Glaze for Stoneware Body. Fired at Cone 7

$$\left.\begin{array}{l} 0.2\ K_2O \\ 0.7\ CaO \\ 0.1\ MgO \end{array}\right\} 0.4\ Al_2O_3 \left\{ 3.5\ SiO_2 \right.$$

Porcelain Body. Biscuited at Cone 07

Florida kaolin	200.0
Eng. china clay M. G. R. No. 1	220.8
Eureka spar	372.2
Flint	207.0
	1000.0

Glaze for Porcelain Body. Fired at Cone 10

$$\left.\begin{array}{l} 0.3\ K_2O \\ 0.7\ CaO \end{array}\right\} 0.4\ Al_2O_3 \left\{ 3.8\ SiO_2 \right.$$

Firing the Trials. The earthenware trials were fired to cone 07 in a small muffle kiln in 6 hours.

The stoneware trials were fired to cone 7 in the large gas-fired laboratory kiln in 24 hours.

The porcelain trials were fired to cone 10 in the same kiln in 36 hours.

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RESULTS

In Table II the writer has attempted to describe the tint of the different colors at the different temperatures:

TABLE II

NO.	CONE 07 EARTHENWARE	CONE 7 STONEWARE	CONE 10 PORCELAIN
A1	Light blue, changing to a dark greenish blue	Sky blue, changing to a deep royal blue	Same as on stoneware
A2			Same as on stoneware
A3			Same as on stoneware
A4			Same as on stoneware
A5			Same as on stoneware
A6			Same as on stoneware
B1	Sky blue, paler than on stoneware, changing to a green blue	Sky blue, changing to a navy blue	Same as on stoneware
B2			Same as on stoneware
B3			Same as on stoneware
B4			Same as on stoneware
B5			Same as on stoneware
B6			Same as on stoneware
C1	Blue gray	Light cobalt blue, changing to a deep navy blue	Same as on stoneware
C2	Gray lilac		Same as on stoneware
C3	Purple blue		Same as on stoneware
C4	Blue		Same as on stoneware
C5	Blue		Same as on stoneware
C6	Blue		Same as on stoneware
E1	Yellow	Greenish yellow	Greenish yellow
E2	Yellow	Darker yellow	Greenish yellow
E3	Yellow	Darker yellow	Greenish yellow
E4	Tan	Canary yellow	Brown yellow
F1	The same colors	but brighter than	those of series E.
F2			
F3			
F4			
G1	Yellow	Ivory	Dirty yellow
G2	Yellow orange	Fawn	Dirty brown
G3	Orange red	Red brown	Chocolate
G4	Red brown	Chocolate	Chocolate
H1	Yellow	Brown gray	Brown gray
H2	Brown	Brown walnut	Brown walnut
H3	Chocolate	Brown black	Brown black
I1	Brownish pink	Gray pink	Gray pink

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TABLE II—Continued.

NO.	CONE 07 EARTHENWARE	CONE 7 STONEWARE	CONE 10 PORCELAIN
I2	Gray green	Brown green	Green
I3	Green	Gray green	Green
I4	Green	Green	Green
K1	Pink brown	Pink brown	Pink
K2	Gray brown	Gray brown	Pink brown
K3	Brown	Brown	Brown
L1	Brown	Pink	Pink
L2	Brown	Pink	Pink
L3	Brown	Brown pink	Brown pink
L4	Brown	Brown	Brown
L5	Brown	Brown	Brown
M1	Blue green	Green gray	Gray green
M2	Blue green	Gray green	Gray green
M3	Green	Brown green	Brown green
M4	Green	Brown green	Brown green

DISCUSSION OF RESULTS

Series A. The colors compounded from alumina and cobalt were good at all temperatures. By using alumina as the base, lighter blues than the usual cobalt blues were obtained. In the case of the highest cobalt content, there was a slight tendency towards a greenish tint on the low fire trials.

Series B. The results of this series were practically the same as those of series A. The zinc increased the greenish tendency at cone 07, but this disappeared entirely upon raising the temperature.

Series C. Flint and cobalt gave decided cobalt blues. They were very uniform in color and behaved well under the glaze. At cone 07, the purple tint of the calcined color body remained to a very slight extent.

Series E. Alumina and uranium gave very pretty yellows under oxidizing and neutral conditions. These same colors gave very pretty grays and blacks under reducing conditions.

Series F. These uranium colors were not so easily influenced by reducing or oxidizing conditions. If one desired one

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of the pretty uranium yellows and also one of the uranium grays in the same fire, the writer is of the opinion that successful results could be obtained by calcining the first color body under oxidizing conditions and the second under reducing conditions, and making the glost burn neutral.

Series G. The iron colors were very good upon being fired to cone 07. As soon as a higher temperature was reached, however, these colors became very unstable and, in the case of the smaller iron contents, entirely disappeared, or left a few dirty spots. The browns at cones 7 and 10 were very good, as they had a large enough iron content to withstand any volatilization loss.

Series H. The colors produced from iron and bone ash were hardly worthy of mention.

Series I. These colors were all good. The most prominent was the chrome-alumina pink, which showed up the best at cone 7 or higher. The green colors were deeper at a lower fire but did not show as delicate tints as those at higher fires.

Series K. Better pinks resulted upon the addition of zinc to series I, but the greens vanished entirely.

Series L. At low fires, none but fairly good manganese browns resulted. As soon as the higher temperatures were reached, however, those of low manganese content gave exceptionally good pinks, while those of higher manganese content retained their brown color but were useless as underglaze colors because of blistering.

Series M. M1 and M2 before the gloss burn were the prettiest sky blue colors that the writer has ever seen. Unfortunately, these lost their beauty, even at low fire, under the glazes used. It would be well worth one's time to investigate these colors with th idea of preserving them under a glaze.

CONCLUSION

The influence of different bases upon different colors are already evident from the discussion of results. In concluding, the writer wishes to emphasize particularly one point brought out in this investigation, and that is the use of small amounts of

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coloring oxides in similar investigations. By using the solution method, small amounts of oxides may be efficiently used, and such results as the beautiful manganese-alumina pinks obtained. In so many investigations, the smallest amount of a coloring oxide used is relatively high, if contrasted to the possibilities of the solution method for dilution, and probably many interesting results have been lost. The beautiful ceramic color, *sang-de-boeuf*, is most effectively producing by using small amounts of copper as the coloring agent, and the possibilities of securing a rival of this color should inspire anyone to give "dilution" a more important place in investigations with coloring oxides.

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THE LEGAL DEFINITION OF VITRIFICATION

BY EDWARD ORTON, JR.

The verb vitrify is an old one, descended from a Latin root *vitrum,* a glass, and *facio,* to make, and hence means literally, *to make glassy,* and we find that this meaning has been transmitted to us, unmodified by all the centuries, so far as the dictionaries go. Stormonth, a very analytical and critical English dictionaire, adds to the above, the idea of how this conversion is accomplished, viz., **"Vitrify, To convert into glass by the action of heat."**

This statement of the origin and the traditional meaning of the word vitrify is important, because in event of controversy the law is invoked to settle it, and a lawyer is the very man to intrench himself behind the barricade of established usage and insist that to vitrify means to make glassy, and that vitrification means the stage of glassiness, or the stage of having been converted into a glass by heat. In this connection it is interesting to note that the word vitrify, which historically should be used by the glassmaker in describing the conversion of his sand and other material into a glass, is practically never so used. The word is foreign to the vocabulary of the glass maker, and its use is now confined almost exclusively to the clay working industry.

But to clayworkers the meaning of the word vitrify has grown away from the original conception in part, in that the idea of glassiness of appearance, at least, is no longer implied. To the clay worker, the word vitrify still means **to convert into a silicate by the action of heat,** but the difference between the present usage and the historic usage lies entirely on the word **glassy.** The silicates produced by clayworkers are not glassy in appearance once in a hundred times, and if the idea of glassiness of appearance is an essential of vitrification, then not one-tenth of a percent of the clay ware now sold in the market as **vitrified,** could make good its title to the term.

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There are two classes of people who use the words vitrify and vitrification frequently: those who make clay products, i. e., ceramic engineers and clayworkers, and those who use clay products, viz., civil engineers, contractors, architects, electricians, purchasing agents and the like. It is to reconcile these two classes of people to the same usage that this paper is written. The users of ceramic materials, having usually no great comprehension of the chemical processes taking place in clay burning, are very prone—in fact almost certain—in event of a dispute, to fall back upon the dictionary to settle whether a clay ware is vitrified or not, and if it is not manifestly vitreous, or glassy, they contend that it is not vitrified, and as the buyer is usually the judge, and can impose his interpretation upon the seller, it happens that frequent and grave injustice is worked upon clayworkers.

The classes of clay products in which the quality of vitrification is important may be grouped as follows:

Bricks	Paving bricks Sewer and sidewalk bricks Impervious face bricks
Tiles	Quarry tiles Encaustic floor tiles Roofing tiles
Pipes and hollow goods,	Sewer pipe Drain tiles
Insulation goods	Electric conduits Electric porcelain goods
Utensils	Porcelain dishware White granite and semi-vitreous dishware

In all of these products, and doubtless others, the specification that the ware shall be "vitrified" or "well vitrified" or "completely vitrified" is commonly written into the buying contract, but in many cases the phrase is not defined by any exactly

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measurable quality of the product. In cases where the meaning of the word is not defined, and controversy arises, who is to say and upon what basis, whether the product is vitrified or not? If the old or historic usage of the word is invoked, as it so often is, then practically no clayware is vitrified. If the modern or technical meaning is applied, the lack of a glassy appearance is no discredit to the ware, but the measureable physical properties of the product will be determined and its status decided upon these measurements.

What qualities, then, does a clayware possess which can be used in defining its vitrification? There are two groups: Visual characteristics and sensible or physically measurable properties.

VISUAL CHARACTERISTICS OF VITRIFICATION

There are two properties, neither capable of accurate measurement, viz.: glassiness or glassy structure, and color.

Glassiness: Dictionaries are very prone to dodge embarrassing questions by defining a property in terms of itself, viz.: glassy bodies are those which have a vitreous fracture, and vitreous bodies are those which have a glassy fracture. All of which sounds well, but doesn't get anywhere. What must a body be, to be rightfully called a glass?

The chief attribute is its fracture, which breaks in smooth, usually rounded surfaces (not planes) intersecting each other at any and all angles, and thus often making sharp splintery edges. These smooth surfaces and sharp edges must be devoid of regular arrangement of particles or structureless, to the unaided eye. In a typical glass, the eye can distinguish no particles, no crystallization, no cleavage, no physical difference between one part and another part.

Transparency is not a necessary attribute of a glass. We have black glasses and white glasses, and opaque glasses of all sorts, but if they have the physical quality defined above, we call them glasses. If, on the other hand, fused silicate masses appear crystalline, or granular, or so divided by cleavage planes as to break with a rough or granular fracture, and with rela-

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tively dull edges, we call them stones or slags, and the stony structure is thus the antithesis of the glassy structure.

It is important to recognize in this discussion that the unaided eye is the criterion. If we employ the microscope, many things appear glassy which are not at all so by the naked eye. Nearly any slag or natural rock, or burnt clay, or fused silicate of any sort, when cut to a thin section, looks like a clear or transparent glass. Even a pocket magnifying glass shows many a stony vitrified slag to be an aggregation of glass-like masses, or like a glassy froth. But the history of a true glass implies that it has solidified from a liquid condition without crystallizing, being what is known in physical chemistry as a "solid solution," while these other bodies which may possess a glass-like appearance under the magnifier, have either never wholly reached the condition of a perfect homogeneous liquid, or having reached it, have crystallized, or segregated, or gone back to a differentiated structure in cooling, and are no longer solid solutions. Naturally, there is room for every stage between the perfectly glassy structure and the perfectly stony or crystallized structure, and thus we have stony glasses, and crystallized glasses, and glassy slags, etc., according to the degree of intermixture of these two states and the history of formation of the substance.

In examining a piece of characteristically vitrified clay ware, we see by the unaided eye a stony mass, opaque, granular or rock-like in fracture, with no keen-cutting or splintery edges. Under the magnifier, we see an aggregation of more or less completely glassy masses, with some considerable residue of particles which have not yet dissolved, the whole never having entirely or even largely reached the liquid state, and therefore being far from a solid solution of the whole original mass of mineral components. In detail, its particles are largely glassy. As a mass it is decidedly not glassy, and it has not had the history of a glass. If a piece of clay ware appears really glassy to the unaided eye, it is an almost absolute certainty that it has been carried much too far along towards fusion, and it is probably of low quality, or valueless for its original purpose.

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Color: Color is not, *per se,* a characteristic of glassiness, since glasses having any of the fundamental colors and indeed of almost any tint or shade, may be made. But, in the case of the vitrification of clays, the process is almost always accompanied by changes in color, and while in a number of different clays there is great variation in the tint produced, at the same stages of vitrification, still in the case of any single clay, its color variation in vitrification is usually a more or less consistent and serial change, and its degree of vitrification can be judged with no little precision by its color, by one accustomed to handling that particular clay. Further, in red-burning clays, as a class the nature of the serial changes are quite similar, and the same is true of buff-burning clays as a class, so that a skilled clay worker would form a conclusion in many cases, with a good deal of confidence, upon a clay with which he was not familiar, by observing its color.

MEASURABLE INDICES OF VITRIFICATION

Structural Density. This does not refer to the true specific gravity of the mass, because this factor varies with the chemical elements represented in the mineral mixture. A clay with an abnormal amount of iron oxide in its composition would show an increased specific gravity from this cause without arguing any greater structural density, just as a lead glass is specifically heavier than a soda glass. Structural density refers to the degree of solidity of structure, i. e., the freedom from either a communicating pore system or a frothy structure due to sealed gas blebs or bubbles enclosed in the mass. The former structure is called **porous** and the latter **vesicular,** and both are inconsistent with structural density, though not necessarily at all inconsistent with a high true specific gravity.

The retention of a part of the pores or communicating system of cavities, is the usual obstacle to development of high structural density in a vitrifying clay product. This property is readily and fairly acceptably measured by the absorption of fluids, on immersing the clay for a given time and observing its percentage increase in weight due to replacing the gas in its

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pores by the heavier fluid. This increase in weight may be translated into percentage of volume of the pores or void spaces to the total space occupied by the solid matter, or percentage porosity. For careful, scientific researches, the percentage porosity may have advantage over the percentage absorption, but as a practical mode of judging the stage of vitrification of a clay, it has no superiority and takes a little longer to make the measurement. It is, therefore, seldom used.

When a clay has been vitrified to a degree approximating actual fusion, its initial system of intercommunicating pores is usually nearly obliterated, but a system of non-communicating gas blebs is developed. These cannot be reached by a fluid and the absorption test becomes useless. There is only one way to get at the percentage porosity of such a body, and that is by means of the difference between its real and its apparent specific gravity. If, for instance, the specific gravity of a cellular mass may be determined as a mass, and then the body be crushed to a fine powder, too fine to permit enclosed gas cells to remain in its individual grains, and the specific gravity of the powder be accurately determined in a pycnometer, then the difference between the apparent and real specific gravity permits calculation of the amount of the real solid matter in the body, and hence the amount of space not so occupied.

Since a clay body in the markedly vesicular stage is obviously unfit for use for the purposes to which vitrified wares are put, it follows that only in rare instances is this calculation employed in practical work.

Hardness. The hardness of a body or the degree to which it resists penetration, cutting or scratching by another body, is a property notoriously difficult to accurately measure. Simple comparative tests are very easily made, but accurately standardized measurements, referable to a single positive scale of hardness, are probably as difficult to make as any physical measurement, and require the most thorough and elaborate standardization of every factor entering into the test.

The hardness of a vitrified clay is furthermore a particularly unsatisfactory measurement, because it is heterogeneous in

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its structure. A typical glass is sufficiently homogeneous so that closely agreeing measurements can be gotten by different observers, but vitrified clays, consist partly of glassy matrix and partly of undissolved grains, usually of hard quartz, but sometimes of soft minerals, and partly of pores or gas blebs. A tool of any sort will, therefore, cut differently at different places according to the matter immediately under it.

In general, the mineral quartz, with a hardness arbitrarily assigned by Moh at 7 in a scale of 10, furnishes the most convenient datum point for rough and ready hardness measurements. Good cutlery steel, well tempered, closely approximates the hardness of quartz, but special steels of greater hardness are now made. Common soda lime glass, used for windows and bottles is between feldspar (6) and quartz (7) and below the best steels and above common or soft steels. Glasses of special hardness can be made, the maximum being glass made of pure fused silica.

The hardness of vitrified clay is, therefore, conditioned chiefly by the hardness of the glassy matrix or fused portion, since this determines not only its own resistance to being cut, but also the resistance which other harder grains offer to breaking out or dislodgement by the cutting tool. A reasonably homogeneous well vitrified clay cannot be cut with good steel any easier than hard glasses can. The steel of the cutting tool wears away in such cases, leaving a streak of the metal in a lead-like line on the clay's surface. Any one can easily acquire some skill in judging the vitrification by procuring a steel knife of good hardness, and practicing the cutting of clay products. In general, a well vitrified clay will resist the attack of a well tempered steel knife, but the knife will cut it readily at all stages below the final one.

Further, over-heating makes a clay vesicular, and this leads to easy cutting, due to the weakening produced by the gas bubbles. Some clays, of poor vitrification behavior, due to preponderance of quartz, or some other mineral, do not acquire good hardness at any stage of burning, even the very best, because of the presence of too little glass cementing matrix to fill up the

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voids and to bind the other materials together. Such clays cut freely with a common knife, whether soft burnt, or when at their best, or when over burnt.

Physical Strength. The ability of a clay body to resist friction, endure blows without chipping, or flexure without breaking, or pressure without crushing, is usually closely associated with the attainment of structural density. But these qualities vary so much in different cases, and develop their maxima at such various points in the scale of vitrification, that they cannot be satisfactorily used for a criterion. Some clays, which never do get at all close to a solid structure, show nevertheless a fine strength. Others which become very dense, are very brittle and weak to impact. Others resist impact well, but won't stand abrasion. Others resist crushing amazingly well, but won't stand either impact or abrasion. Thus while it is usually safe to say that if clay shows high physical strength, it will also show good density of structure, and that these occur at about the same point in the heat treatment, it is frequently not borne out. Also while it is usually safe to assume that if a clay shows very low physical strength, it will not show good density of structure, this is often not true, due to checks, or cooling cracks weakening a structure otherwise strong.

THE NATURE OF THE VITRIFICATION PROCESS

We have seen that the abstract or theoretical conception of a perfectly solid homogeneous solution represented by a perfect glass is never realized or realizable in the case of a clay product, and that the word "vitrified" is not applied in actual usage to the class of bodies which could attain such an ideal state, but is applied to another class of bodies which cannot. The process of vitrification is the process of silicate formation, or the process of merging the ingredients of a heterogeneous mineral mixture into a homogeneous solid solution of silicates. But there are a number of factors which are at work in this process, and an understanding of them will aid us in getting a conception of vitrification itself.

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Influence of Mineral Composition. To every chemist, it is at once obvious that the possibility of forming a solid solution will depend in any given case on the minerals present in the mixture, and on the temperature available. Any mixtures of minerals can be fused to a quiet liquid solution in the electric arc, but at the ordinary temperatures atained in kilns and commercial furnaces, only properly constituted proportions of acids and bases are fusible. It would carry us too far to go into this question carefully, but it may be said that only mixtures in which the proportions run from that of the orthosilicates (oxygen ratio 1:1) or a little below, up to the trisilicates (oxygen ratio 1:3) or a little above, will fuse easily. Any clay which is greatly overloaded with quartz sand, or with large proportions of carbonate of lime, or almost any other common mineral, is thrown out of these fusible ratios, and hence vitrifies with great difficulty, and with a very imperfect degree of vitrification at best. It is not only not at all uncommon in practical work to find clays which will work well for ordinary porous clay products such as building bricks, and still will not vitrify to anything approximating industrial requirements, but it may fairly be said that there are more clays used industrially which fall outside of the commercially vitrifiable class than fall in it. By this it must be understood, not that any of these clays could not be converted to a reasonable perfect solid solution, by use of adequate heat and time, but simply that the process would cost far more than it would come to, and is therefore commercially impossible.

Preparatory Steps. In addition to the mechanical preparation of clays, by which the mixture of minerals is ground fine, and made less coarsely heterogeneous, the preliminary stages of burning are vitally important in preparing the minerals to combine and fuse into a solid solution. The original minerals are of all sorts—silicates, both hydrous and anhydrous; oxides; hydroxides; carbonates; sulphides, free carbon and hydrocarbons, and in short anything in the mineral list. By the time the temperature reaches 900°C, these compounds should have been converted into stable forms, all volatile bodies like sulphur

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should have been driven out, easily decomposible salts like carbonates should have been broken down to oxides, all oxides should have been converted into their most stable form, all combustible matters should have been burnt out and carried off as gases, and nothing should be left except what may enter into a silicate solution.

If these preparatory steps are not taken with sufficient deliberation, and thoroughness, so that the clay begins to vitrify before they are completed, the result is a very bad type of vitrification. The body formed becomes vesicular before it has attained its normal color, or strength or density, and no finishing point for the kiln can be found at which the product possesses satisfactory commercial vitrification.

Progress of the Vitrification Process. Assuming that the clay was properly prepared before the vitrification temperatures were applied, the normal beginning of the reaction is from little spots or foci, here and there throughout the body. Each focus is represented by some easily fusible mineral grain, or the juxtaposition of two or more mineral grains which conbine to form a eutectic or the most fusible ratio in which these minerals can combine. When in either case a minute quantity of fused material is formed, it attacks surrounding grains, dissolving or bringing them into its own slag, each focus thus cementing the surrounding grains of matter together with a glassy or silicate cement. If there is much material present which is coarse grained and difficult of fusion, and too little material to make the glassy cement, then the body remains porous, as in the case of very sandy clays. If the material suitable for forming the fluid matrix is very abundant and fine grained so that the foci overlap each other, the process goes on with too great rapidity, and the deformation point of the mass as a whole is soon reached and the mass begins to sink out of shape early, as in the case of the slip clays.

Shrinkage. In general, the spread of the glassy cement from focus to focus in a clay of good vitrifying character is slow and steady, and the proportion of grains which will not readily dissolve is such that they form a sort of skeleton or frame work,

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holding the mass in its shape, while the glassy cement slowly encompasses them and fills up the voids, causing the well known phenomenon called shrinkage. Deformation takes place in such a clay, only when the skeleton of undissolved grains is cut through in enough places to make a slow collapse of the structure begin. On the other hand, shrinkage without deformation takes place from the beginning of the vitrification process. It is slow or rapid, according to the above factors. The total volume change is likewise great or small from the same causes.

Swelling. Another factor which strongly influences the vitrification process and conditions the quality of the product, is the swelling reaction. Practically all silicates when passing from the solid state to a state of complete fusion, give off some gaseous matter. It may be gas which they have held in solution and which is then occluded, or it may be from remnants of volatile matter not hitherto expelled, or it may be due to the swelling of gases caught in the interstitial voids of the mass during the shrinkage, and unable to escape. Probably all three causes are responsible in most cases. Undoubtedly the second cause is the one reponsible where the process is hurried. These gases, whatever their source, tend to act upon the gradually softening silicate mass exactly as baking powder acts upon dough. This swelling agency is at work as soon as the formation of glassy cement begins. At first the gas vesicles are microscopic, and do not exert much effect. But as more glass forms, and it becomes more fluid, the gas bubbles expand, and decrease the effect of the shrinkage which the gradual fusion tends to cause. If carried to a state of even incipient fusion, where the mass is merely soft enough to deform a little, the mass usually increases in size over its initial volume. In many cases, the swelling is inordinate, reaching four or five times the initial volume.

The Refining Stage. If this process of fusion be carried along steadily until a fluid bath is obtained, the liquid will pass into a frothy stage in which the gas bubbles work their way to the top, and escape. Glass in this stage, often runs out of the pot, onto the furnace floor. But with continued heat and liquidity, the bubbles finally cease to form, the liquid settles down, and

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the silicate takes its minimum volume. At this stage in glass making, the glass is said to be refined, and is then cooled down to a properly viscous stage for blowing. Of course, clay wares never pass through the refining stage. If they reach the beginning of this stage at all, they are sure to be deformed past all usefulness and complete refining means fusion to a thin liquid and holding in this state till all working is over and the fluid is quiet.

Complete Vitrification. From the above it can be seen that the clay product, in reaching its point of greatest density, does not reach the point where the gases are fully expelled, but only the highest point attainable **without causing their evolution to seriously begin.** This maximum density is found at a point where the reduction in volume due to shrinkage is equalized by the expansion due to gases evolved. One force balances the other, and for a time the volume of the clay remains constant. This time may be long or short. In some clays of most excellent vitrifying habit, a heat treatment represented by five or six cones may occur, with scarcely any change in size. In others, the volume diminishes rapidly and at the minimum point begins at once to swell again, with no appreciable interval. Such clays cannot be burned profitably into hard products. There is no margin in which the burner can regulate his kiln, and a part of every kiln would surely be over-fired and bloated, part would be at its best density, and part would be underfired and not up to the best density. Such clays are said to have a short vitrification range.

The important thing in this is to remember that a clay at its best stage of density is at that stage for a short temperature interval at best, and that the so called "complete vitrification" of a clay product is an absolutely different thing from the complete reduction to a solid solution reached in the case of a glass.

It is also important to remember that no clay at its densest stage is devoid of gas cavities. It has millions of them, mostly microscopic and mostly non-communicating, but is likely to have also some vestiges of its former communicating system remaining, so that it can still absorb some water. Only in rare cases

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in coarse clay products, can absolute impermeability to water be secured. In fine porcelain bodies, impermeability of a higher order is procurable, due to the composition and better preparation, but even here it is not likely to be absolute.

Recapitulation. First: We have seen that the right of a burned clay to the title "vitrified" is not easily defined. Vitrification is seen to be a process, rather than a state of being, and that perfect density of structure is an unattainable ideal.

Second: A glassy fracture or a glassy appearance to the unaided eye is positively not a characteristic of a good clay product.

Third: That clay products which are visibly glassy are practically certain to be overburned and worthless.

Fourth: That all clay products, whether well vitrified or vitrified but little, show glassy portions or a glassy matrix under magnification.

Fifth: That the color of the product offers only a partial guide to the stage of vitrification, and one only useful to a person having very full knowledge and experience.

Sixth: That the hardness of the product offers only a very partial guide to the stage of vitrification, because of the difficulty of measuring it, and because of the heterogeneous nature of the clay body.

Seventh: That physical strength, under impact, friction or pressure is not necessarily directly proportional to vitrification, and that many clays develop their best strength at points distinctly above or below their best structural density.

Eighh: That structural density is by far the best criterion of vitrification, and that no clay product of low structural density can be considered well vitrified, and vice versa.

Ninth: That every clay in burning passes from a stage of low structural density, through a stage of the increasing structural density up to a maximum, and then more or less rapidly, into a stage of still lower structural density, in which condition it is worthless as a clay ware.

Tenth: That the vitrification range during which any given clay is at its best structural density is a function of the mineral

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make-up of the clay itself, and its treatment in burning, and while it may be shortened greatly by bad treatment, it cannot be greatly extended by care.

Eleventh: That the physical qualities of different clays taken at their best stage of structural density vary greatly, and that the greatest vitrification which some clays can attain is too low to make them suitable for heavy duty.

Twelfth: That the absorption test is the simplest and most generally satisfactory criterion of the structural density of a clay product.

DEFINITION OF STANDARD

In view of the foregoing, it seems obvious that we are really using the word vitrified in two senses. In the participial usage, we call a clay completely vitrified, when it attains its best physical state, i. e., its greatest structural density, and this regardless of what particular degree of density this happens to be. In the other, or adjective usage, a clay is called vitrified only when it has a certain degree of structural density, regardless of what it is capable of having.

If it were feasible to abandon the use of the word entirely in this last sense, and replace it with some new expression which would avoid this constant confusion, it would be better to do so, but there seems to be no likelihood of being able to do this. The word is too thoroughly rooted in our technical practice.

Different Standards for Different Wares. It will at once be apparent that for every one of the different kinds of products listed in the early part of this paper a different degree of vitrification might properly be required, and therefore different absorption percentages be set. No one would contend that the absorption limits set for high voltage electric insulators need be exacted for sewer pipe or paving bricks. In fact, limits have been set in private and public contracts for a long time past, and quantities of such wares have been bought and sold on specifications, which require such a degree of impermeability as will not permit of the forming of a red ink spot on a fresh fracture of ware in some kinds of goods, down to one permitting five percent or six percent absorption for others.

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The greatest injustice which has been done in this connection is done among the more ignorant buyers and the more ignorant sellers. Thousands of dollars worth of sewer pipe, drain tile, roofing tile, and bricks of various sorts, are sold annually where the specifications merely provide that the product shall be "vitrified," but do not specify what degree of vitrification will be exacted. Then, when some envious and disappointed bidder raises the question afterwards, and the City Council, or Engineer, or Director of Public Improvements, or County Commissioners are obliged to rule on what "vitrified" means, there is all kinds of chance for injustice.

I believe that the American Ceramic Society is the logical body to take the initiative in this matter. Any definition, made by us or by any other organization or individual, is a purely artificial matter, or fiat. It becomes law only by general acceptance, and because the public has confidence in the ability of those who decide.

I therefore proposed the following for the consideration of the Society:

Where the word vitrified is used in a contract or agreement as an adjective in describing the properties of a clay product, without further definition in the contract, it shall mean that the product shall have attained in the firing process such a degree of structural density that its mean absorption will not exceed three (3) percent of its own initial weight of pure water, when subjected to absorption tests of forty-eight hours' complete immersion in cold water, or three hours' immersion in boiling water. Not less than three tests shall be made in determining the mean absorption, and no single test may exceed the mean by more than one-half percent. Neither the possession of the visual properties or appearance of a glass, nor any definite degree of physical strength, hardness, color, or specific gravity shall be implied as an attribute of vitrification.

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DISCUSSION

Mr. Bleininger: It is a rather curious coincidence that several weeks ago I received a letter from a Western sewer-pipe concern regarding the definition of vitrification, and that we gave the exact limits as stated by Professor Orton.

Mr. Potts: I also gave the same limits of vitrification in rejecting a batch of sewer pipe just before Christmas, 1913.

Mr. Jackson: I should like to ask Professor Bleininger whether there is not some recognized test which covers the question of vitrification from the viewpoint of the purchaser of such ware.

Mr. Bleininger: So far as I know the actual purchase of pottery is based on visual inspection. I want to say, further, that we have a good many specifications in the government service that are never used at all.

Prof. Silverman: There is one point that I should like to mention in connection with your color-absorption test, with which we experience considerable difficulty in glass, viz., that the surface itself will resist the action of solutions, while with slight scratching you get good absorption. So you might have a surface coating that would prevent absorption and put the article in the class specified by your conditions, yet the moment weathering had removed that surface coating, it would be out of the class due to greater absorption. That would not hold good in very porous materials but would in the more glassy.

Another point is a suggestion to enable you to differentiate porosity due to communication between the spaces and that due to bubbles. The general porosity might be determined by placing a piece of material in an inverted tube full of mercury, so that the mercury would cause the gas in the communicating pores to be released for measurement. After this take the piece and place it in a steel mortar, fitted with a connecting gas tube. Close the vessel by means of a rubber washer. The pestle itself is encased in a heavy rubber tube. You can thus do your crushing after the mortar has been evacuated. In this way, you first remove the gas in the communicating pores and subsequently measure the gas volume of the enclosed pores, due to the glassy

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structure itself. Thus you can differentiate between communicating pores and bubbles.

You may have occasion to use such a method, as there is the possibility of differentiating between the two kinds of spaces. The apparatus was constructed by Dr. Francis C. Phillips, of the University of Pittsburgh, and is used for a similar purpose in the analysis of minerals.

Mr. Staudt: As a manufacturer of white vitrified floor tile, I think that I should get into serious trouble if my tile would absorb as high as three percent of water. The architects have already defined the meaning of the word "vitrified" as to vitreous floor tile, by specifying non-absorbant. to make sure of this, the architects test the tile by means of ink. If the ink washes off readily, the tile are considered non-absorbant; if, however, the ink leaves a spot on the tile, the architects claim that they are absorbant. To claim that the tile do not absorb more than three percent of water would not hold good. I would simply be shown the ink-spot and be told that the tile are absorbant, whereas specifications read: "tile to be non-absorbant."

Mr. Lovejoy: On the other hand, if three percent were the maximum limit a number of paving brick manufacturers would have to go out of business.

Mr. Stull: In regard to the ink test, if that test is to continue in use, it ought to be standardized. Results depend upon the kind of ink used. Some inks require vigorous rubbing to remove them from a glazed surface, while other kinds will wash off readily.

Mr. Staudt: They take almost any kind of ink in making the test, in some cases they have used red ink, which seems to contain a sharper acid than does the black ink. I came across a tile on which black ink would wash off freely whereas red ink left a stain.

Mr. Minnemann: In regard to the ink test, I think that it is unfair to a certain extent, because the kind of fracture controls the amount of ink left on the piece. In a stony body, which may be just as dense as a piece with conchoidal fracture, the fracture will often fill with ink that you are unable to wash

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off as you could in a glassy piece. In two different materials, there may be two different kinds of fracture.

Mr. Denmead: I think I can add something to help prove Mr. Minnemann's statement. It is a habit among our engineers to get a piece of porcelain from the works and immediately dip it into ink, leaving the ink on until the next day. We have tested seventy-five pieces treated in this way and have found that although it was impossible to wash the ink off, yet there was not an absorption of .03 percent in any one piece.

Mr. Bleininger: A dilute solution of oxalic acid following the ink test removes all ink on the surface, but the ink that has gone in will not be touched by the acid.

Prof. Silverman: I want to emphasize in this connection the necessity for standards and especially the need of having a committee appointed for this purpose. I tried to bring that about last year in regard to glass, and Professor Orton is after the same thing in his field. I suggest that a number of committees be appointed to prepare specifications.

Mr. Humphrey: I can see where an injustice might be done if an amount of three percent should be established as a dividing line between vitrified and unvitrified paving block. All engineers want vitrified brick. Some inexperienced or ignorant engineer might specify and rigidly hold to a three percent absorption specification, which would exclude some good makes of pavers from his market. Or it might unjustly cause the manufacturer a lot of expense and trouble. The injustice would be done where a broad general definition is applied to a special case where it will not fit.

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EFFECT OF SOME ELECTROLYTES ON CLAY[1]

BY ROBERT BACK

INTRODUCTION

Applications of the technical control of clay disperse systems are made in many branches of the ceramic industries and in the settling of mud and slimes in the metallurgical industries. In the ceramic industries, a knowledge of disperse systems is applied in casting pottery ware, in making glass pots, and in the manufacture of zinc muffles and gas retorts, large crucibles for steel industries, glass-furnace materials, and furnace blocks. It is an aid in the problems of fitting slips or engobes and glazes to clay bodies, and also in the improvement of clays by increasing or decreasing plasticity and in the removal of objectionable coloring bases and other troublesome substances. The knowledge may be of aid also in obtaining a satisfactory method for measuring the plasticity of clays. The concentration of mineral slimes may be accomplished by the removal of clay or clayey substances by electrolytic processes.

There are many other purposes for which colloidal clays are used, and still others for which they may be used, such as the drilling of wells by the mud-laden fluid method.[2]

The work represented by this paper was carried on for the purpose of studying the effects of dilute solutions of electrolytes on plastic clays such as are used in pottery making and allied industries, and correlating, if possible, the observed results with facts already known regarding disperse systems. The paper is published by the Bureau of Mines as one of a series on mineral technology.

Laboratory experiments were made with clay in the following four conditions: as a plastic mass, such as is used in turning pottery ware; as a paste with a consistency like that of vaseline; as a clay slip of creamy consistency, such as is used in casting

[1] Published by permission of the Director of the Bureau of Mines.
[2] Pollard, J. A. and Heggem, A. G., Mud-laden fluid applied to well drilling. Tech. Paper 66, Bureau of Mines, 1913. 22 pp.

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pottery ware; and as a dilute mixture, consisting of 5 grams of clay in 100 cc. of water or a salt solution.

With the plastic clay, the effects produced on the volume shrinkage in drying were studied by varying the content of water and keeping that of the clay constant, and also by adding electrolytes to the plastic clay, while the proportion of water to clay was kept constant.

With clay in the form of vaseline-like paste that would not flow, the effects of adding electrolytes were studied, the water content being increased or decreased so that the paste was made just fluid enough to flow from a funnel.

In the case of the clay slips, viscosity determinations were made, a modification of the Mariotte tube being used, and the effects of some electrolytes on the viscosity of the slips were determined, the clay and water contents being kept constant. The flocculating influence of electrolytes of different valency on the dilute clay and water mixtures were studied; possible sources of error in viscosity measurements were ascertained, and a procedure followed that, as far as possible, would eliminate errors in making such measurements. The volume shrinkages of the casting slips on drying were also determined, varying quantities of electrolytes that deflocculate the slips being used and the viscosity of the slips being kept constant for all the tests by using the same weights of clay with varying quantities of water.

Mechanical analyses of the clays were made, and the malachite-green absorptions were determined so that the surface-factor values and the relative colloid values for the different clays could be compared.

EFFECT OF ELECTROLYTES ON CLAY IN THE PLASTIC STATE

In view of the fact that the literature of clay technology contains practically no statement of the effect of electrolytes on clays in the plastic state, it was decided to make a careful attempt to obtain some numerical values. The volume shrinkage of clay briquets dried under constant conditions was used as the criterion of the effect of electrolytes on the plastic clay. This

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was done because it is widely believed that any salt that changes the surface tension of the liquid medium and consequently its viscosity, or effects a change in the state of the colloidal content of the clay, will manifest such effects best in the variation of volume shrinkage. It is known that shrinkage is a function of plasticity, and that the degree of plasticity is intimately associated with the proportion and kind of liquefying medium as well as the physical condition of the clay constituents.

Method of Procedure in Making Tests. The procedure followed was to prepare a thoroughly mixed sample of the clay, dry this sample at 110°C., allowing it to cool in a desiccator, and then weighing out portions large enough to make, with given weights of salts and water, plastic masses for molding briquets. After a thoroughly worked mass of the desired plastic consistency had been prepared, it was stored in a moist chamber for 24 hours in order to make reasonable allowance for any time effect.

The plastic clay was molded in a brass form into briquets 10 by 2.5 by 1.56 cm., which were at once weighed and then immersed in petroleum, the volume being measured in a volumenometer a few hours later. For each concentration of salt, three briquets were made and measured. The specimens were then allowed to dry at the laboratory temperature for three days, and were then heated to constant weight in an oven, the temperature being regulated by a thermostat at 110°C. The dried briquets were at once weighed and immersed in petroleum until completely saturated, when they were placed in the volumenometer for the determination of the shrinkage on drying.

Determination of Proportions of Water Used. In order to establish the limits of the working consistencies of the clays used, samples of the clays were made up into briquets representing the extremes of the plastic state, that is, so dry at one end of the series that the mass could barely be worked, and as wet at the other end as the clay could be made and the briquet still retain its shape when handled. The drying shrinkages were then determined as usual. Tests were made with a kaolin from Georgia, a kaolin from North Carolina, and a ball clay from Tennes-

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see. The effects on the shrinkage of varying the water content is shown in Figure 1.

These curves illustrate the short range of working consistency of the two kaolins as compared to the much longer range for the ball clay. For the full line curves, the percentages of water are calculated from difference in weight of the wet and dry briquets, whereas for the broken line curves, the percentages of water as actually added to the clay in mixing was used. It is evident that the plotted points which show crosses are more or less in error. The curvature of the North Carolina kaolin curve differs from that for the Georgia kaolin and the ball clay, showing that for a given increase in the percentage of water, the increase in volume shrinkage is greater in the two latter clays than in the North Carolina kaolin, especially for the higher percentage of water used with each clay. Also for any given volume shrinkage, there is a much greater difference between the percentages of water on the full line and broken line curves for the North Carolina kaolin than there is for the Georgia kaolin curves. The difference is about four percent for the North Carolina curves, which is nearly as much as the greatest difference for the ball clay curves, thus showing that for the highest percentage of water used with the North Carolina clay, about 9.45 percent of the total water content is retained as hygroscopic and pore water, and for the lowest percentage of water, 9.75 percent. The respective figures for Georgia kaolin are 4.5 percent and 4.7 percent, and for Tennessee ball clay, 10.85 percent and 5.00 percent.

That there should be only a slight difference in the two figures for both of the kaolins and such a marked difference for the ball clay indicates that the ball clay differs radically in structure from the kaolins. The finer grained ball clay retains a larger proportion of hygroscopic and pore water for the decidedly plastic state than for the drier or barely plastic state, by virtue of its fineness of subdivision, which presents a greater proportion of minerals in the colloidal state than either of the coarser grained kaolins do. It is also noted that the percentage of hygroscopic and pore water in the North Carolina kaolin is more than twice that in the Georgia kaolin, which fact is the most probable cause

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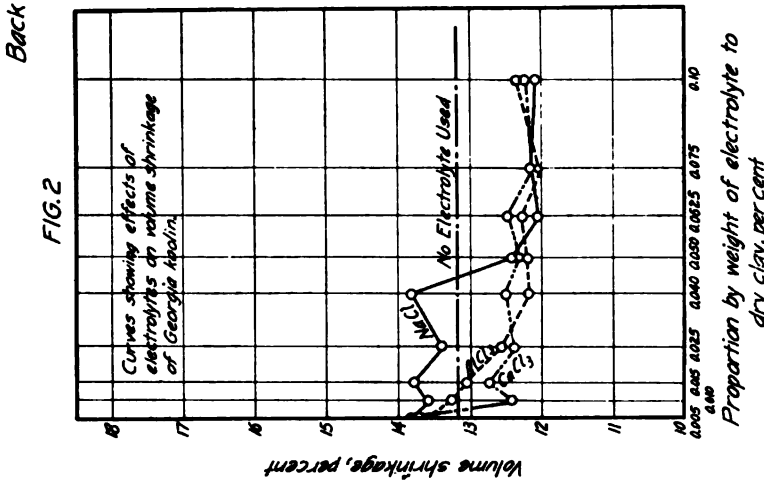

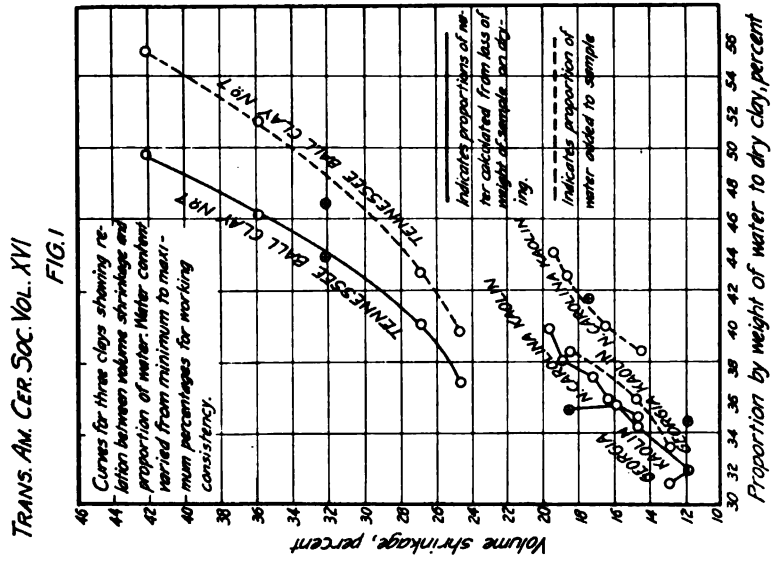

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of the difficulty in fitting a clay slip containing North Carolina kaolin to a clay body. The middle point of each curve represents the most satisfactory molding condition for each clay. Taking this point in the ball clay curve and the Georgia kaolin curve, it is observed that the ratio of percentages of water is 48 : 36.4= 1.32 : 1, while the ratio of volume shrinkages is 31.6 : 15.2= 2.08 : 1.

Tests with Georgia Kaolin. Effect on Volume Shrinkage. The effect of NaCl, $CaCl_2$, and $AlCl_3$ on the volume shrinkage of plastic samples of Georgia kaolin is shown by the curves in Figure 2.

It is noted that both $CaCl_2$ and $AlCl_3$ are more effective than NaCl in proportions less than 0.04 percent. A NaCl content of 0.05 percent brings about the same decrease in shrinkage as smaller proportions of the other chlorides. The tests indicate also that 0.005 percent of any of these reagents causes approximately an increase in shrinkage of one-half percent more than that for water alone, equal quantities of solutions and water being used. Bleininger[3] says, that "the cause of the dual behavior of the electrolytes is to be sought in dissociation phenomena." The writer of this paper offers the following explanation: The slight increase in shrinkage resulting from the use of the smallest percentages of electrolytes can be attributed to a lowering of the surface tension or a change in the viscosity of the liquid—the liquid medium—sufficient to cause a slight deflocculation that renders the volume of the liquid medium more than enough to give the degree of plasticity obtainable with distilled water and no electrolyte. According to Purdy,[4] deflocculation of purest clay grains takes place when the surface tension of the liquid medium is less than that of pure water. Consequently, the shrinkage must increase over that represented by the pure water curve until the concentration of the electrolytes causes flocculation, when, for the same volume of liquid medium used, the shrinkage decreases. When the concentration of these three salts was 0.05 of 1 percent, the maximum effect on the shrinkage

[3] Bleininger, A. V., The Effect of Electrolytes upon Clay in the Plastic State. Original Communications, *Eighth Intern. Cong. Appl. Chem.*, Vol. 5, 1912, p. 24.

[4] Purdy, R. C., Qualities of Clays Suitable for Making Paving Brick. *Illinois Geol. Surv.*, Bull. 9, 1908, p. 191.

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of plastic Georgia kaolin was approximately reached, the shrinkage being practically constant for greater concentrations.

The dissociation of the salts and the effects of their electrolytic properties show more appreciable results in the tests with dilute mixtures of clay and solution, described on another page.

According to Rohland,[5] such chlorides as NaCl and $CaCl_2$ should be entirely neutral, but the tests seem to indicate that they are rather active in affecting the efficiency of the liquid medium in a plastic clay and, as will be shown later, they display decided activity in clay in the state of a suspended slip.

Bleininger[6] states: "The use of NaCl is of special interest in this work, since experiments carried on in this laboratory showed that in the case of exceedingly plastic clays of tertiary origin, the plasticity was greatly decreased by the use of salt solution, which was strikingly demonstrated by their drying behavior. Briquets made from the untreated clay cracked and checked very badly, while specimens made up with a NaCl solution dried normally without the slightest evidence of cracking and at the same time possessed a greatly reduced drying shrinkage."

Effect on Proportion of Water Retained in Drying. In order to determine to what degree the relation between shrinkage and pore water is affected by the reagents used, the total and the shrinkage water were calculated in terms of the true clay volume. For this purpose, the density of the powdered clay was determined by means of a pycnometer, using the usual precautions. The volume of the shrinkage water was then calculated from the evident relation:

$$\frac{100\,(V_1-V_2)\,d}{W_1}=\text{Percentage of shrinkage water (by volume)}$$

where,

V_1 = volume (cubic centimeters) of wet briquet;

V_2 = volume (cubic centimeters) of dried briquet;

W_1 = weight (grams) of briquet dried at 110°C.; and

[5] Rohland, P., On the Putrefaction of Clay. *Ztschr. anorg. Chem.*, Vol. 41, 1904, p. 329; On the Influence of Hydroxylions on Kaolin Suspensions, *Koll. Ztschr.*, Vol. 2, 1912, p. 193-4.

[6] Bleininger, A. V., The Effect of Electrolytes upon Clay in the Plastic State. Original communications, *Eighth Intern. Cong. Appl. Chem.*, Vol. 5, p. 24.

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d =density of clay.

Similarly, the following equation holds,

$$\frac{\text{Total water (cc.)} \times 100d}{W_1} = \text{percentage of total water (by volume)}.$$

In this equation, total water (cc.) is equivalent to $(W_2 - W_1) \div 1$, W_2 being the weight of the wet briquet, and the density of the water being taken as 1. The percentage of total water minus the percentage of shrinkage water equals the percentage of pore water. These calculations show that the addition of salts decreases the shrinkage water volume 10 to 11 percent and increases the pore-water volumes 3 to 4 percent of the average volumes obtained when salts are not added. As the difference in weight of either the wet or dry briquets was not more than 1 percent, and as the volume measurements for duplicate pieces did not differ more than 0.2 to 0.6 percent, it seems justifiable to attribute the variations in the proportion of shrinkage to pore-water to the effect of the reagents, manifested in a rearrangement of the clay particles, or a change in their power for retaining water at a temperature of 110°C. The latter effect is caused by the reagents changing clay sols to gels and thus increasing the absorptive power of the clay for water.

EXPERIMENTS WITH ELECTROLYTES AND CLAY AS THICK PASTE

Experiments were made to determine the variation in water content necessary with different concentrations of electrolytes to cause clay pastes of Georgia kaolin and Tennessee ball clay No. 1 respectively to flow from a small funnel, drop by drop, one drop for every 10 to 15 seconds. Twenty-five grams of clay were dried for 3½ hours at 110°C., and placed in a jar. The clay was made into a paste by stirring with water or water plus electrolytes until the above consistency was obtained when transferred to the funnel. The funnel had a 2-inch stem of about 4 mm. bore. Those concentrations of electrolytes were used which showed marked changes or maximum and minimum points in the curves plotted for the viscosity work with the Mariotte tube. The results are given in Figures 3 and 4.

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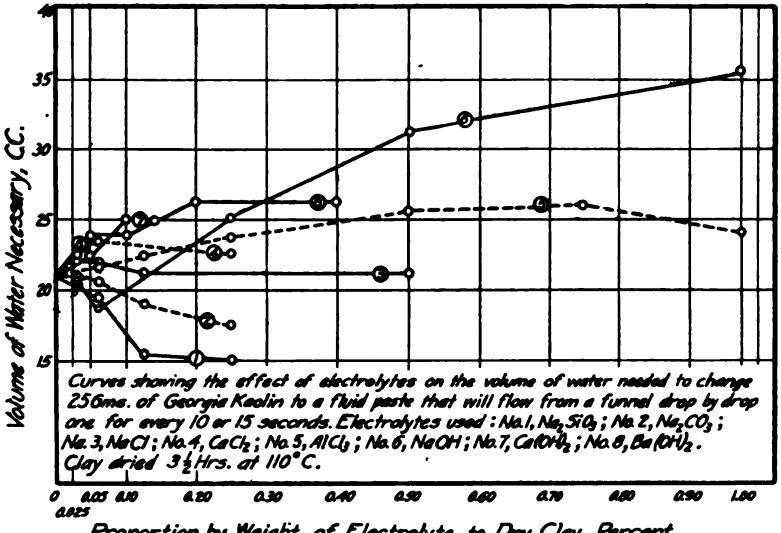
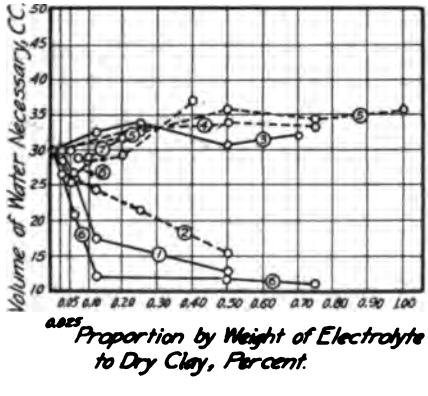
FIG. 3



Curves showing the effect of electrolytes on the volume of water needed to change 25 Gms. of Georgia Kaolin to a fluid paste that will flow from a funnel drop by drop one for every 10 or 15 seconds. Electrolytes used: No. 1, Na_2SiO_3; No. 2, Na_2CO_3; No. 3, NaCl; No. 4, $CaCl_2$; No. 5, $AlCl_3$; No. 6, NaOH; No. 7, $Ca(OH)_2$; No. 8, $Ba(OH)_2$. Clay dried 3½ Hrs. at 110° C.

FIG. 4



Curves showing effect of electolytes on volume of water needed to change 25 Gms. of Tennessee Ball Clay No. 1 to a fluid paste that will flow from a funnel, drop by drop, one for every 10 to 15 seconds. Electrolytes used: No. 1, Na_2SiO_3; No. 2, Na_2CO_3; No. 3, NaCl, No. 4, $CaCl_2$; No. 5, $AlCl_3$; No. 6, NaOH; No. 7, $Ca(OH)_2$; No. 8, $Ba(OH)_2$. Clay dried 3½ Hrs. at 110° C.

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With Georgia kaolin, Na_2SiO_3 and Na_2CO_3 in small concentrations had the strongest influence in reducing the quantity of water needed, whereas the effect of NaOH was similar to that in the viscosity measurement tests with Georgia kaolin described elsewhere in this paper. The Na_2CO_3 and the Na_2SiO_3 additions produced a very syrupy and sticky mass that would easily flow from the funnel. With Tennessee ball clay No. 1, Na_2SiO_3, Na_2CO_3, and NaOH in small concentrations had a marked effect in reducing the proportion of water needed. $Ca(OH)_2$ and $Ba(OH)_2$ in proportions of 0.05 to 0.10 percent also reduced the necessary water content to a smaller extent. (Fig. 4.)

The influence of these electrolytes on the surface tension of the liquid medium, and the corresponding flocculating and deflocculating effect on the clay minerals, explains in part the results of the work as represented in Figures 3 and 4. The pronounced effect of the NaOH, KOH, and the easily hydrolyzed salts, Na_2SiO_3 and Na_2CO_3 is due to the hydroxyl-ions they furnish, and the possible solution of organic compounds.

THE FLOCCULATION OF DILUTE MIXTURES

The flocculating effect of the three chlorides, NaCl, $CaCl_2$ and $AlCl_3$, on Tennessee ball clay No. 1 and Georgia kaolin in dilute mixtures (5 grams dried clay in 100 cc. of mixture) are shown graphically in Figures 5 and 6, respectively. The effects are self-evident from these curves, and it is observed that the coagulating power of these salts is in the order of their valency. Also coagulation took place more rapidly with $CaCl_2$ and $AlCl_3$ than with NaCl.

In this work, the general procedure was as follows: The dilute mixtures were agitated for one hour in a rotating machine and then allowed to stand over night until apparently the maximum settling had occurred. The number of c.c. of sediment and of turbid and clear solution were determined, and curves plotted as given in Figures 5 and 6.

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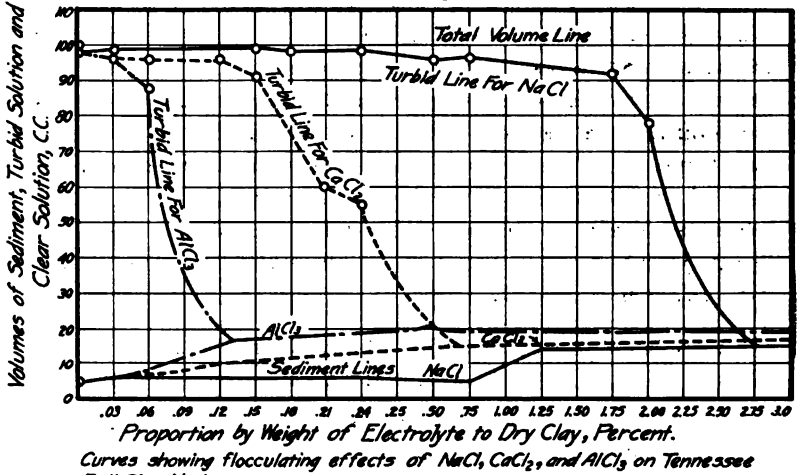
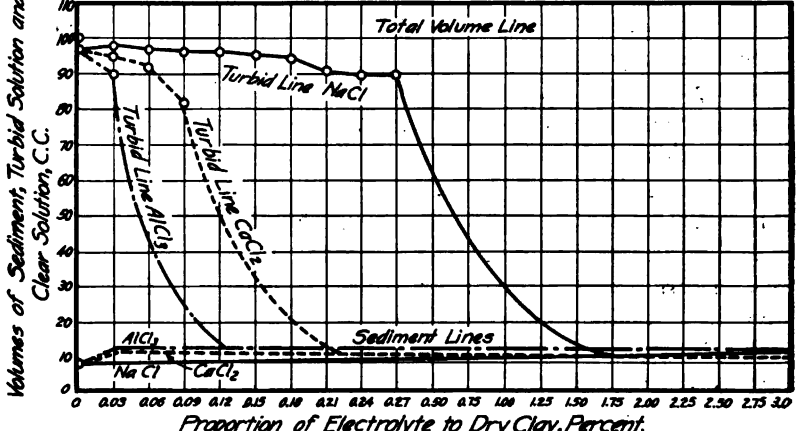
FIG. 5



Curves showing flocculating effects of NaCl, $CaCl_2$, and $AlCl_3$ on Tennessee Ball Clay No. 1.

FIG. 6



Curves showing flocculating effects of NaCl, $CaCl_2$, and $AlCl_3$ on Georgia Kaolin.

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MECHANICAL ANALYSES AND MALACHITE GREEN ABSORPTIONS

Mechanical analyses of both Georgia kaolin and Tennessee ball clay No. 1 were made with the Schoene elutriating apparatus after first deflocculating the 5-gram samples of clay with sodium hydroxide solution. From the results of the analyses, the total surface factors were calculated and found to be 61.33 for Tennessee ball clay No. 1 and 40.94 for Georgia kaolin. The ratio of the two total surface factors is approximately 3:2. This coincides closely to the ratio of relative colloids between these two clays which, as determined by the malachite green absorption test, was 66 : 39.23.

VISCOSITY MEASUREMENTS OF CLAY SLIPS USING ELECTROLYTES

The effect of electrolytes on Tennessee ball clay No. 1 and Georgia kaolin, in the state of slip consistency was studied by making viscosity measurements with a modification of the Mariotte tube as shown in Fig. 7.

Fifty grams of dried clay with 100 cc. distilled water was selected as a standard slip.

Determination of Possible Sources of Error. Experiments were performed to determine the probable sources of error in making viscosity determinations.

Figure 8 shows that the clay samples must be dried at least 3½ hours at 110°C. in order to have a slip of uniform viscosity for all tests with electrolytes. From the curve, it is evident that the colloidal structure of clay is much affected by drying at 110°C. The colloid substance is probably partly changed to a set or less active condition of collected molecules of gel-formation of decreased hydration, in which the more finely subdivided colloidal content is not so readily dissociated and rehydrated by the addition of water. Hence the colloid gels give a much lower value for viscosity than clay heated for shorter periods. On the other hand, coagulation due to electrolytes increases the viscosity values. These results tend to confirm the theory that drying a clay dehydrates the colloidal substance, and hence in this case

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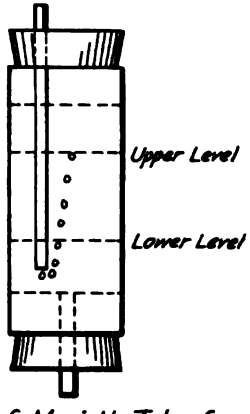
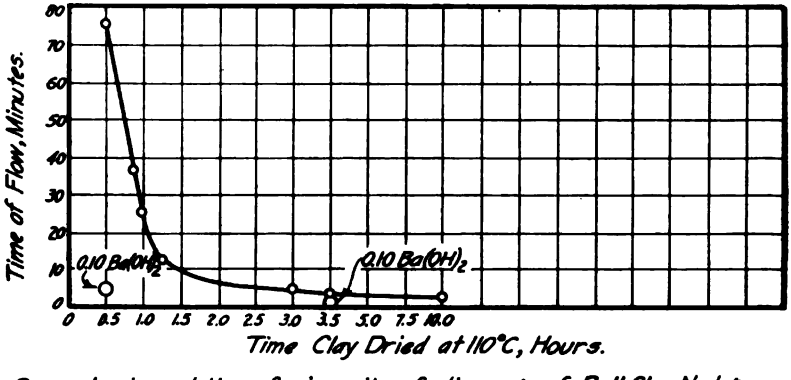
FIG. 7



Modification of Mariotte Tube for Determining Viscosity of Clay Slips.

FIG. 8



Curve showing relation of viscosity of slip made of Ball Clay No. 1 to length of time clay is dried at 110°C. Equal quantities of clay are dried for the tests.

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more water is available as a diluent for the dried clay of decreased activity, leaving the dispersive medium less viscous and consequently lowering the viscosity of the given volume of clay slip, as shown by the curve. This effect cannot be due to the driving off of mechanical water alone, for in that case the thoroughly dried clay should require much more water to obtain the same degree of viscosity. But with a freshly made slip of the dried clay, the viscosity is lower with the same water content. The colloid structure must have been partly set and dehydrated. The large circles on Figure 8 show that the addition of 0.10 percent of $Ba(OH)_2$ lowers the time of flow for a given quantity of slip to 4½ minutes for clay heated only one-half hour at 110°C., and to 2¼ minutes for clay heated 3½ hours. This shows that a small percentage of $Ba(OH)_2$ deflocculates the system, when the clay is not heated long enough for dehydration of the colloidal substance, and thereby lowers the viscosity of the slip nearly to that of the slip made with the clay heated for the longer period. With the clay dried 3½ hours the 0.10 percent of $Ba(OH)_2$ also deflocculated the system slightly, as shown by the other large circle above the 3.5 mark.

Tests were made to determine whether variations in temperature, quantity of water used, or time of standing of the slip were possible sources of error in making viscosity determinations with the Mariotte tube. Tennessee ball clay No. 1 was used in making the slips. The tube used for the tests had a bore of 6 mm. diameter. The results are given in the curves of Figure 9.

A temperature variation of 15°C. had no appreciable effect. Variation of water content had a marked effect on the viscosity of the slip. An addition of two percent of water reduced the viscosity by 4.08 percent; of four percent of water, 9.18 percent; and of nine percent of water, 28.57 percent. However, in all the viscosity tests of clay slips in this paper, the water contents agreed within one percent, a difference which would affect the viscosity measurement by only about two percent.

With clay dried only one or two hours at 110°C., a considerable error is introduced by allowing a slip to stand an hour or longer before testing. The viscosity is noticeably increased

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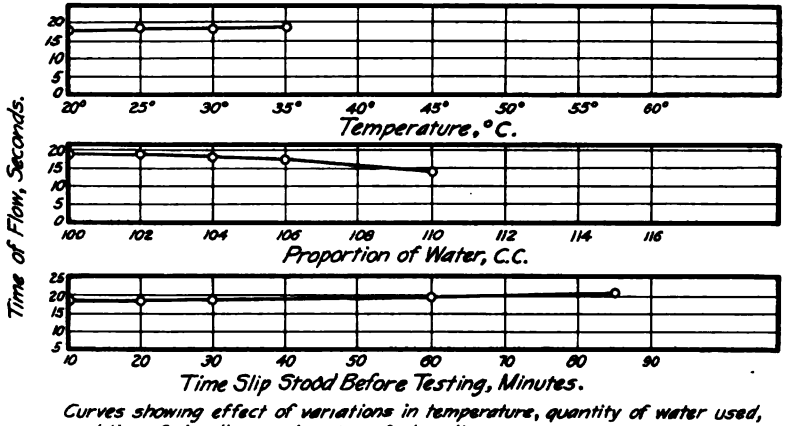
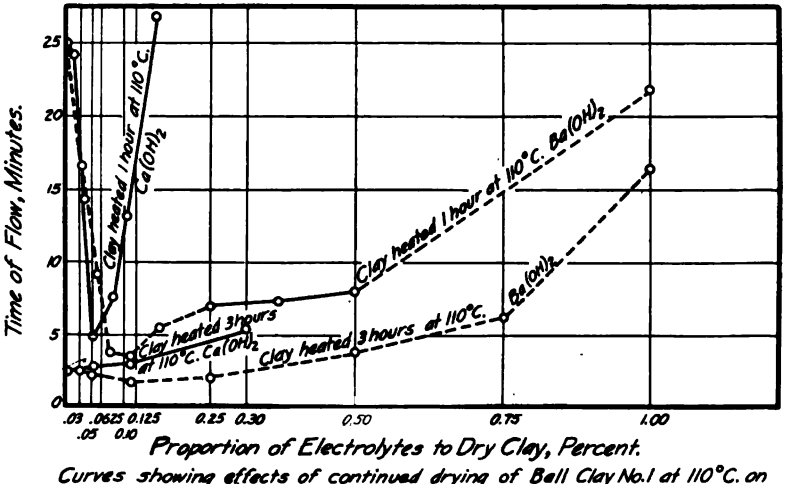
FIG. 9



Curves showing effect of variations in temperature, quantity of water used, and time of standing on viscosity of clay slips.

FIG. 10



Curves showing effects of continued drying of Bell Clay No. 1 at 110°C. on results of tests with electrolytes. Slip made with 50 gms. of Dry Clay and 100 c.c. of Water.

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by long standing, because the colloidal substance is again hydrated, and the disperse medium becomes more viscous. If the clay is dried 3½ hours or more at 110°C., the increase in viscosity due to standing in an air tight jar is hardly noticeable even after 24 hours, if 0.50 percent NaOH be used, as shown in the test described on page 534. But if distilled water alone be used, the viscosity is appreciably increased on long standing, but not as rapidly as with clay heated for a shorter period. However, the final viscosity of a slip made with clay that had been heated for the longer period and allowed to stand until a maximum hydration was again obtained and the viscosity had reached a constant value, would most probably be greater in value than the final viscosity for a slip made of clay which had been heated for the shorter period at 110°C., unless permanently set organic colloids had been produced. The viscosity tests were made immediately after the thorough mixing of the slip, and the viscosity values obtained for repeated tests were constant.

Figure 10 shows the effect of $Ca(OH)_2$ and $Ba(OH)_2$ on ball clay No. 1 slips, made with clay which had been heated at 110°C. for one and three hours respectively. The curves clearly show how misleading data would be obtained in viscosity measurements, if constant quantities of clay samples were not dried at 110°C. to a constant viscosity value with water alone, before testing the effects of any electrolyte solutions on the clay slips.

In all the following work on viscosity tests with the Mariotte tube, the quantity of drying clay was kept constant, the temperature was kept at 110°C., and the clay was dried at this temperature for three or four hours until the approximately constant time value of 2¼ to 2½ minutes for the efflux of a constant quantity, by volume of a slip was obtained. This drying treatment of all clay samples was then adhered to as the standard for viscosity work.

Tests with NaCl, $CaCl_2$ and $AlCl_3$. The curves in Figure 11 illustrate the effects which NaCl, $CaCl_2$ and $AlCl_3$ have upon the viscosity of slips made with Tennessee ball clay No. 1. All three salts apparently act as flocculating agents and consequently increase the viscosity of the clay slip. The $AlCl_3$ shows a

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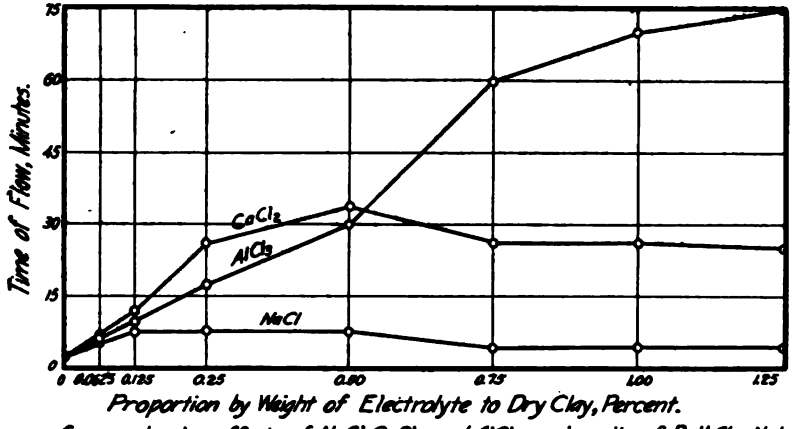
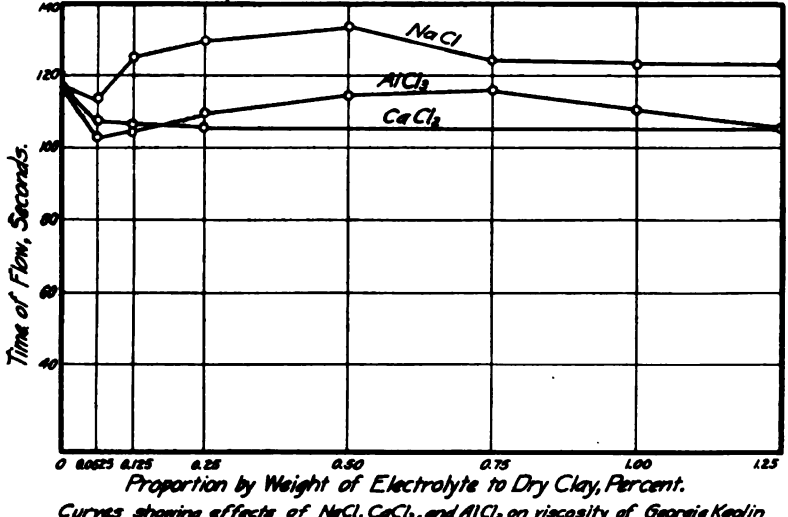
FIG. 11



Curves showing effects of NaCl, $CaCl_2$, and $AlCl_3$ on viscosity of Ball Clay No.1 slips. Slip made with 50 gms. of dry clay and 100 c.c. water.

FIG. 12



Curves showing effects of NaCl, $CaCl_2$, and $AlCl_3$ on viscosity of Georgia Kaolin slips, slips made with 50 grams of dry clay and 100 c.c. of water.

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marked increase in viscosity for the higher concentrations which can possibly be accounted for by the fact, that $AlCl_3$ is readily hyrolyzed to HCl, and $Al(OH)_3$. The HCl accelerates coagulation by its content of H+ ions. The $Al(OH)_3$ may be partly acted upon by alkali salts present in the clay, to form soluble aluminates, until equilibrium is obtained. For concentrations of NaCl and $CaCl_2$ greater than 0.50 percent, the viscosity is lowered slightly.

The effects of NaCl, $CaCl_2$, and $AlCl_3$ upon the viscosity of Georgia kaolin slips are shown in Figure 12. The viscosity is lowered for the smallest concentration of those salts used, somewhat in the order of their valencies, because of a slight deflocculation. C. f. Fig. 2 and page 520. The flocculating influence of any of these salts is, however, not as manifest with Georgia kaolin, as it was with the ball clay, because possibly, of the fact, that the thorough drying rendered the colloidal substance comparatively inactive. The time of flow is plotted in seconds in order to magnify the variations in viscosity. Tests with neutral salts should be repeated several times in order to verify the effect of these salts on the viscosity of slips. These tests were made only once and checked once for each concentration of salt. It may be mentioned, that the effect of even neutral salts will vary with different clays, which may be due to the kind and condition as well as the quantity of colloidal content in the clay.

Effects of $Ca(OH)_2$, $Ba(OH)_2$, NaOH and KOH. Tests with Ball Clay No. 1. Figure 13 shows the flocculating influence of $Ca(OH)_2$ and $Ba(OH)_2$ upon Tennessee ball clay No. 1, the former being the more active flocculating agent. Considerable iron is present in this ball clay, and possibly the following changes take place:

$$3Ca(OH)_2+Fe_2(SO_4)_3=3CaSO_4+2Fe(OH)_3$$
$$3Ba(OH)_2+Fe_2(SO_4)_3=3BaSO_4+2Fe(OH)_3$$

Less soluble salts of calcium and barium are thus formed along with insoluble and gelatinous ferric hydroxide precipitate. This may account for $Ba(OH)_2$ showing a greater flocculating effect on the ball clay slip than on the Georgia kaolin slip. The

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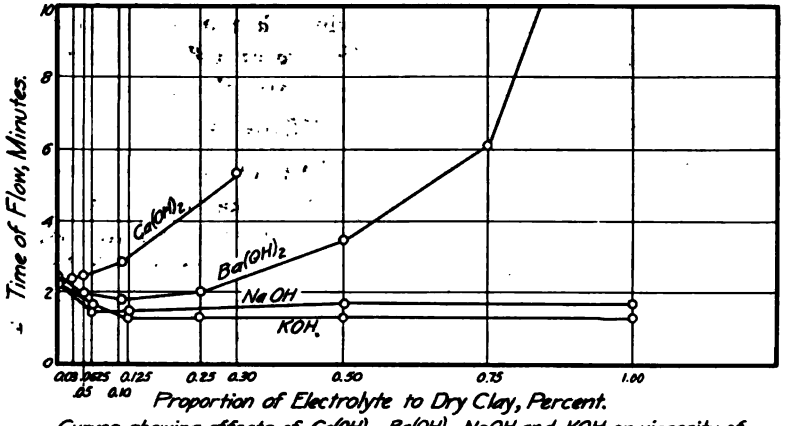
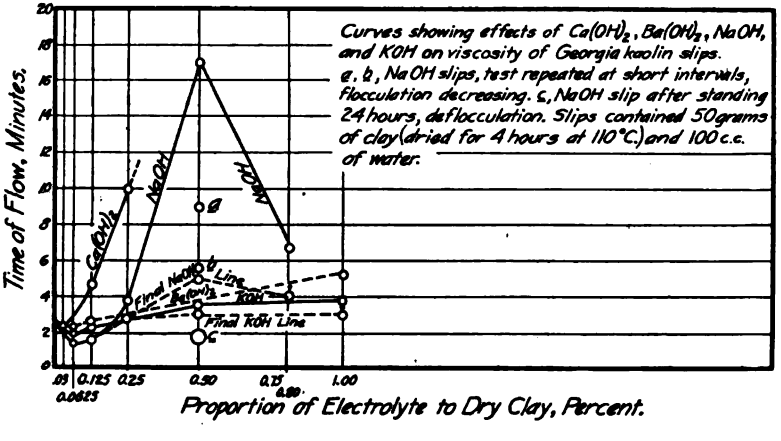
FIG. 13



Curves showing effects of $Ca(OH)_2$, $Ba(OH)_2$, NaOH and KOH on viscosity of Ball Clay No. 1 slips. Slip contained 50 grams of clay (Dried 3½ hours at 110°C.) and 100 c.c. of water.

FIG. 14



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$Ca(OH)_2$ was not soluble enough for using more than 0.30 percent by weight of it in solution for the slips tested. Higher percents would undoubtedly have brought the curve sharply upward. NaOH and KOH are vigorous deflocculating agents. It will be noticed that $Ca(OH)_2$, which has a lower molecular weight than $Ba(OH)_2$, is more effective as a flocculating agent than $Ba(OH)_2$, whereas KOH of greater molecular weight than NaOH is a more effective deflocculating agent than the latter.

Tests with Georgia Kaolin. The effects of these same four electrolytes upon slips made with Georgia kaolin are shown in Figure 14. $Ca(OH)_2$ seems to show greater flocculating power, and $Ba(OH)_2$ a little less so than with slips made with Tennessee ball clay No. 1. Thus it is evident that $Ba(OH)_2$ not only prevents efflorescence, or scumming of burned products from the soluble sulphates present, as other investigations have proved, but also tends to increase plasticity. With concentrations greater than 0.125 percent of NaOH and KOH, the immediate effect of these hydroxides on the kaolin slip was that of flocculating agents. With 0.50 percent NaOH, flocculation was very pronounced, but the effect speedily diminished on repeating the viscosity tests with samples of the same slip, as shown by the small circles, *a*, *b*. Tests were made at short intervals until a comparatively constant viscosity could be plotted, as shown by the broken line. After this slip had stood open to the air for 24 hours, its viscosity was again determined. The value obtained, shown by the large circle *c* indicates that after the elapse of some hours during which the slip had been in contact with air, the NaOH became a deflocculating agent, as happened in the case of slips of Tennessee ball clay No. 1.

At least part of the cause for this unstable effect of the hydroxide can be attributed to the formation of the strong deflocculating agent, Na_2CO_3, by the absorption of CO_2 from the air. When contact with air is not allowed, the viscosity values for the different concentrations of NaOH and KOH are not appreciably decreased, but remain close to the values as shown by the full line curves.

The viscosity values for $Ca(OH)_2$ and $Ba(OH)_2$ were fairly

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constant for one hour after first testing, during which contact with air was allowed, but no tests were made after these slips had stood for longer periods.

It is possible that the $Ba(OH)_2$ acts somewhat as a deflocculating agent compared to $Ca(OH)_2$, according to the following reaction as given by Ashley:[7]

$$Ba(OH)_2+CaSO_4=BaSO_4+Ca(OH)_2$$
$$Ca(OH)_2+CO_2 \quad =CaCO_3+H_2O$$

The action may be on alkali sulphate, according to the reaction, $Ba(OH)_2+Na_2SO_4=BaSO_4+2NaOH$, and hence that of deflocculation by NaOH. Accordingly, the $Ba(OH)_2$ would not show its flocculating influence and stabilize the colloid gels, until the soluble sulphates are changed, as shown above, to insoluble $BaSO_4$.

Böttcher[8] while doing similar work experienced what he called super-stiffening of his slips, and Ashley[9] offered "delayed chemical action" as an explanation. The following is offered as an analysis of this action.

The lime or possible rare earths of the kaolin is probably acted upon as follows:

$$2NaOH+Ca^{++}gel=2Na^{+}gel+Ca(OH)_2.$$

If contact with air is not allowed, the colloidal substance remains coagulated owing to the activity of the $Ca(OH)_2$ formed, thus giving a high viscosity. Otherwise the following reaction takes place: $Ca(OH)_2+CO_2=CaCO_3+H_2O$, in which case, the stabilizing influence of the lime is reduced to a minimum, because the $CaCO_3$ which is formed is comparatively insoluble, and the reaction goes forward almost to completion before equilibrium is reached. Further absorption of CO_2 then goes to form the deflocculating agent Na_2CO_3, with the soda gels, and thereby causes a change of the colloidal substances in the system from

[7] Ashley, H. E., The Technical Control of the Colloid Matter in Clays, *Trans. Amer. Cer. Soc.*, Vol. 12, 1910, p. 785.

[8] Böttcher, M., The Liquefaction of Clays by Alkali, *Sprechsaal*, Vol. 42, 1909, pt. 1, pp. 133-135.

[9] Ashley, H. E., The Technical Control of Colloids in Clays, *Trans. Amer. Cer. Soc.*, Vol. 12, 1910, p. 790.

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the gel to the sol state, and deflocculation, with subsequent reduction of the viscosity results. If rare earths have been precipitated by NaOH, this formation of the Na_2CO_3 would effect their solution again. With excess NaOH, the influence of the lime is overbalanced, and the deflocculating effect of the Na_2CO_3, that is formed, occurs immediately, as shown by the initial NaOH curve in Figure 14. The action with Georgia kaolin is not as marked when KOH is used. Similar reactions take place, but the action is not so decided nor so much delayed as with NaOH, possibly because K^+ ions are heavier than the Na^+ ions and migrate with greater speed. It would be interesting to observe whether lithium hydroxide would cause a still greater delay in this action, for the Li^+ ion has an atomic weight of only 7. and its speed of migration is less than that of the Na^+ ion. Böttcher's[10] work gives some foundation for this reasoning, for it took a smaller molecular equivalent of LiOH than either NaOH or KOH to produce this immediate increase in viscosity or "super-stiffening," as he calls it; and the viscosity or stiffness of LiOH slips of the higher concentrations was not as thoroughly reduced after 24 hours standing as was that, of both the NaOH and KOH slips. The results of tests by Böttcher do not show such a marked difference between the use of NaOH and KOH as those of tests by the author, but the slips used by Böttcher were much thicker, 50 grams of clay per 64 cc. of water, which may account for the difference. It is evident that the speed of migration of the ions plays an important part in reactions for colloidal clay solutions containing electrolytes. In this case, the rapidity of the deflocculating action, that is effected by the absorption of CO_2, would be in accordance with the speed of migration of the ionic form of the electrolyte used, and also with the relative activity of lithium, sodium, and potassium in the absorption of CO_2 from the air.

Tests with Na_2CO_3 and Na_2SIO_3. Figure 15 shows the liquefying or deflocculating influence of Na_2CO_3 and Na_2SiO_3 upon the slips of Georgia kaolin and Tennessee ball clay No. 1.

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[10] Böttcher, M., The Liquefaction of Clays by Alkali, *Sprechsaal*, Vol. 42, 1909, pt. 1, pp. 133-135.

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FIG. 15

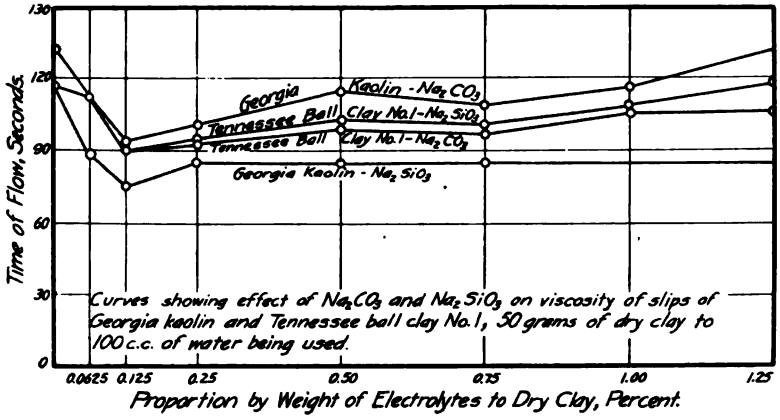
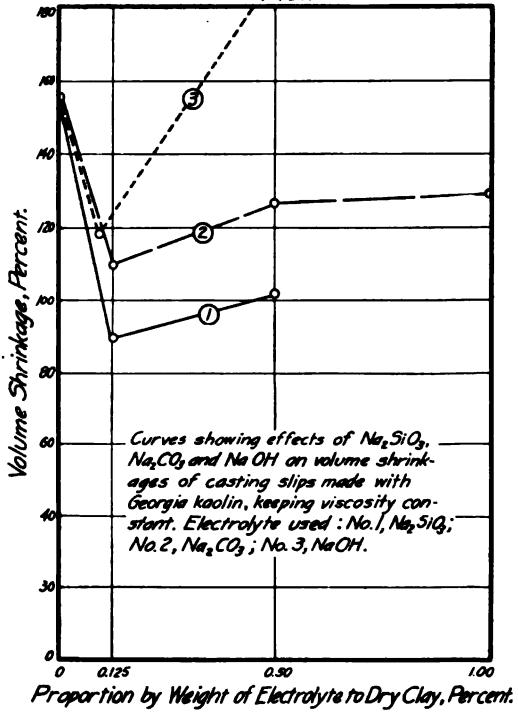


FIG. 16



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Only 0.125 percent of these reagents is necessary to give minimum viscosity which corresponds to maximum deflocculation.

This concentration of Na_2CO_3 and Na_2SiO_3, used half and half, should be used with a slip of this viscosity in casting work to reduce the quantity of water needed and consequently the shrinkage. For slips of greater or lesser viscosity, the proportion of deflocculating reagent would be increased or decreased slightly. Using the same kind of Mariotte tube for measuring the viscosities of clay slips, Green and Baugh[11] found that it took about 0.6 percent Na_2CO_3 and Na_2SiO_3 to obtain a minimum value of viscosity, using 68 grams of clay to 110 cc. of water, and allowing 200 cc. of slip to flow from the tube. The author found that the velocity of outflow changed appreciably for the denser slips, as the slip lowered in the tube. In the author's tests, smaller volumes of slip were taken, and the time required for the slip to sink in the tube from one level to the next was observed. Between these levels the velocity of efflux is practically constant.

VOLUME SHRINKAGE OF CASTING SLIPS, USING ELECTROLYTES

A series of tests were made in order to determine the effects which Na_2CO_3, Na_2SiO_3 and NaOH have upon the volume shrinkages of casting slips. The results of these tests are given in Figures 16 and 17.

The shrinkage is greatly affected by 0.125 percent of electrolytes, Na_2SiO_3 having the greatest influence. With Georgia kaolin, not more than 0.50 percent of the Na_2SiO_3 could be used, for the cast body became so weak in structure that it could not be removed from the mold in one piece. The sample of slip with 0..50 percent NaOH in it was allowed to stand 24 hours excluded from the air, before it was tested, and made up to the constant viscosity used as a standard in the casting tests. The Georgia kaolin slip had stiffened as in the test described on page 534, and considerable water had to be added in order to get the standard viscosity before casting. This is the cause of the

[11] Mellor, J. W., Green, S. A., and Baugh, T., "Studies on Clay Slip," *Trans. Eng. Cer. Soc.*, Vol. 6, 1905-07, pp. 165-166.

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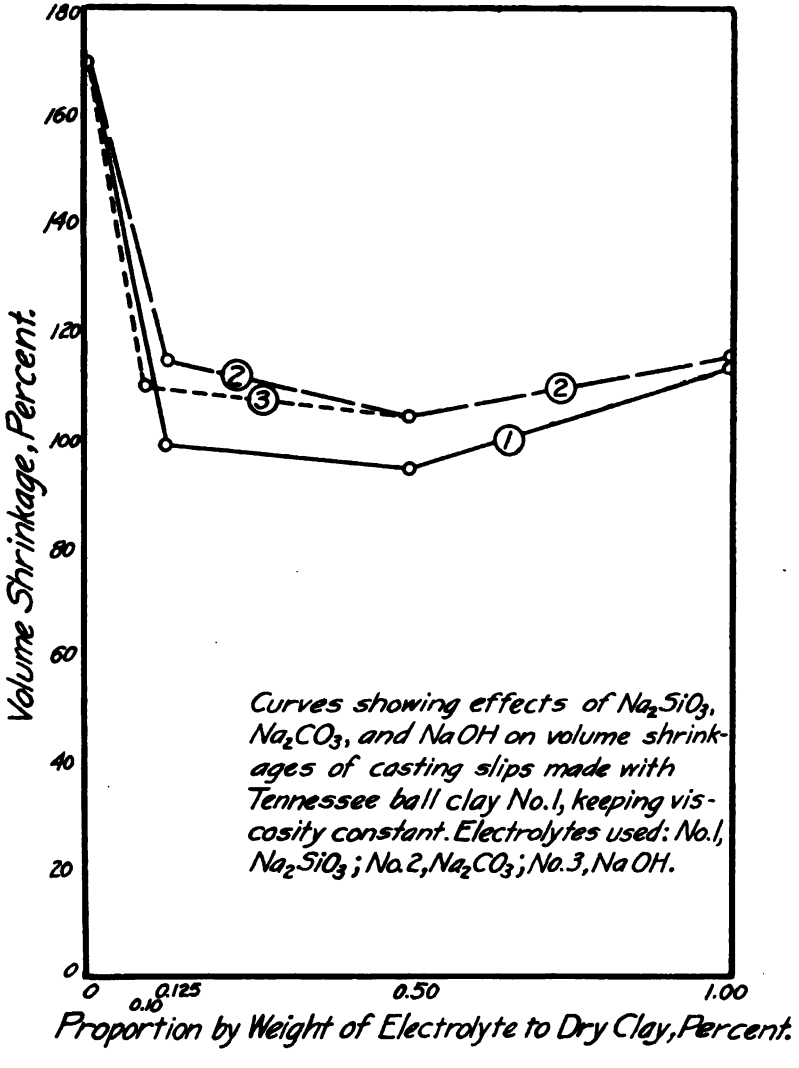
FIG. 17



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NaOH curves for the two clays being different. If the carbon dioxide in the air had been allowed to affect the kaolin slip which stood for 24 hours, the shrinkage would have been greatly reduced, making the NaOH curve more like the other curves in Figures 16 and 17.

In this work the clays were dried, to give a constant viscosity for a definite quantity of water, and then slips with electrolyte solutions were made up to this constant viscosity by varying the quantity of water used. Before settling could take place, the slips were drawn from a burette into plaster of Paris molds, care being taken to use the same volume of slip to fill the molds. The shape of the cast pieces when dried is shown in Figure 18. The volumes were determined in the usual way after first soaking the dried pieces in kerosene over night. The use of the larger quantities of electrolytes caused thorough deflocculation of the slips. The dried cast pieces, when broken, showed how completely the fine colloidal material had separated from the larger grains of clay. These grains settled to the bottom of the cast piece, and the fine colloidal clay settled on top. Such thorough deflocculation by destroying homogeneous structure, as illustrated in Figure 18,, tends to weaken the piece. The dried cast pieces of Tennessee ball clay containing 0.5 percent of NaOH and 0.5 and 1 percent of Na_2SiO_3 showed hardened, dull-black surfaces owing to the accumulation of either colloidal carbon or dissolved organic substance drawn to the surfaces by evaporation.

The writer suggests another method for the determination of plasticity values. The method involves the formula $P=CxBxV$ in which C is the relative colloid value, determined by the Rodenwald-Mitscherlich hygroscopicity method, B is the volume shrinkage of the dried cast clay-slip, and V is the viscosity value of the clay slip determined by the efflux method. According to Stremme and Aarnio, the hygroscopicity determination is the most satisfactory method for gauging the colloidal content of clays. Since lime and alkalies are believed to affect the malachite green used in the dye-absorption method, these men prefer the hygroscopic method. The formula involves consideration of

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the absorption, shrinkage, and viscosity of a clay. The fineness of subdivision and the presence of absorbed salts will show their effects individually on the value of each of the factors, and it does not seem necessary to introduce any other factors to account for those effects.

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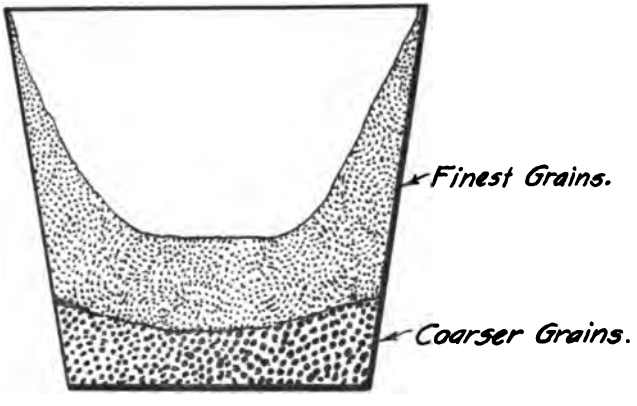
FIG. 18



Showing structure and shape of the dried cast piece.

It is necessary that the clay samples be dried according to some definite procedure, and the following method is recommended:

The clay should be dried in constant quantities of about 250 or 300 grams in an oven with the temperature maintained at 110°C. The material should be distributed evenly in a flat pan and placed in the oven so that all samples dry uniformly. The drying at 110°C. should continue, until a definite weight of clay, after having been cooled in a desiccator then made up into a slip with a selected weight of water and shaken uniformly for five

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minutes in a jar, will give an approximately constant viscosity value with the Mariotte tube. This dried clay, as soon as it has cooled to a room temperature in a desiccator, should be used for the determination of each of the factors C, B and V.

For the determination of the factor B, a comparatively low viscosity value should be chosen as a standard, by producing a slip that flows readily from an efflux tube with a small orifice. Then, by using a given weight of dried clay with an unknown weight of distilled water at room temperature, a clay slip should be made up to obtain the standard value of viscosity, as follows: An insufficient quantity of water is first used with the given weight of clay to make a slip of approximately cream-like consistency, which should be agitated for one hour in a rotary machine, run at the rate of about 30 revolutions per minute. The slip is then allowed to stand in an uncovered jar for 24 hours, when the required quantity of water should be added and mixed thoroughly to give the standard value of viscosity. Definite weights of this uniform mixture should then be cast in plaster of Paris molds for the determination of the volume shrinkage. The best procedure is to use a burette containing a little more than the required quantity for one of the cast pieces, and draw the uniformly mixed slip from the burette into a mold. This should be overbalanced in a scale pan by a weight that is equal to the weight of slip to be used for the casting. The volume of slip taken for each casting must be carefully measured and recorded. The cast pieces are then dried in the molds for 48 hours at room temperature, and, thereafter at 110°C. in a drying oven until the weight of each cooled piece is constant. The pieces are then immersed in kerosene until they are thoroughly saturated with the oil and all of the inclosed air bubbles are driven out. The time required is 12 to 15 hours. The volumes are then measured accurately in a volumenometer, a modified form of that used by Seger, and the shrinkage B is calculated as a percentage of the dry volume.

The value of factor V is determined by the time of efflux from the Mariotte tube of a given volume of slip made from standard proportions of water and properly dried clay. This

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slip is first agitated for one hour in the rotary machine and then allowed to stand in a covered jar for twenty-four hours before its viscosity is determined. In some future work the writer hopes to test the accuracy and usefulness of the foregoing procedure for determining the plasticity values of clays and ceramic mixtures. If factors B and V are carefully determined, it is believed that their products alone may give values that afford an accurate comparison of the plastic properties of a series of clays. Viscosity has been used by Bleininger[12] as a measure of plasticity with fair results.

SUMMARY

1. In making tests with electrolytes on clay in the plastic state, the greatest precautions are necessary to eliminate error, especially in drying the clay, making it plastic, and molding it into briquets. The volumetric measurements are easily kept within the allowable limits of error.

2. For the best working consistency, the ratio of the volume shrinkages between the ball clay and the Georgia kaolin is 2.08 : 1, whereas the ratio of the percentages water used is 1.32 : 1, thus showing that there is no relation between these factors. The hygroscopic and pore water of the North Carolina kaolin is more than twice that of the Georgia kaolin, and almost as much as that of the Tennessee ball clay.

3. The cause of the dual behavior of electrolytes is to be sought in dissociation phenomena and the changes in surface tension of the liquid medium.

4. Electrolytes that cause flocculation in a clay system may often be employed to reduce cracking and excessive shrinkage in the drying of troublesome clays.

5. The varying shrinkage and pore-water volume relations can be attributed to an arrangement of the clay particles effected by the reagents, or to a change in their power for holding water which will not evaporate at 110°C.

6. The smallest percentages of electrolytes used, show in-

[12] Bleininger, A. V., The Viscosity of Clay Slips, *Trans. Amer. Cer. Soc.*, Vol. 10, 1908, pp 389-395; Vol. 11, 1909, pp. 596-605, Note on the Viscosity of Clay Slips.

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creased effectiveness upon the fluidity or stiffening of a clay when it is in the form of a paste.

7. The coagulating power of neutral salts and also the rapidity of coagulation increased with their valency.

8. In viscosity work, strict precautions are necessary to eliminate error, especially in reference to the procedure of drying the clays and as regards the range of time involved in making tests.

9. Neutral salts as well as acids and alkalies have decided influence on the shrinkages and viscosities of clays.

10. In proportions less than about 0.05 to 0.075 percent $Ca(OH)_2$ and $Ba(OH)_2$ act as deflocculators but greater concentrations have a decided flocculating effect, the $Ca(OH)_2$ being of greater influence with the two clays tested.

11. NaOH and KOH are vigorous deflocculating agents for all concentrations, although with some clays a temporary flocculating or thickening effect may be produced which can be explained by the presence of lime and other stabilizing substances. It is also evident that the atomic weights of the elements and consequently the speed of migration of their ions play an important part in the rapidity of reaction for colloidal clay solutions.

12. NaOH and KOH also may be used for casting slips with approximately equal effectiveness to that obtained with Na_2SiO_3 and Na_2CO_3. The volume shrinkages are reduced to only 60 to 65 percent of what they would be without the addition of these electrolytes. The structure of the cast piece seems more compact and stronger when the correct quantity of electrolytes is used, but the use of too much weakens the piece.

The author gratefully acknowledges his indebtedness to A. V. Bleininger for helpful suggestions.

DISCUSSION

Mr. J. B. Shaw: In the enamel iron industry, when they make their enamels with five to ten percent of ball clay, they always add what we call tempering material in order to bring the enamel slip to the consistency of cream. It does not run.

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This tempering material makes it short, and is what we call tempering. In enamel, that consistency must be obtained in order to get the enamel on the ware in a uniform coat.

I developed an enamel last spring which gave great trouble in tempering, although the same clay was used as in the ordinary factory practice. Satisfactory tempering was not obtained with the use of borax or magnesium sulphate. Instead of bringing the enamel to the consistency of cream, the tempering materials seemed to make the enamel run more poorly than if nothing had been added.

I should like to know, in the light of these experiments, why these tempering materials acted differently in the case of this special enamel and the regular factory enamel. The only difference in the enamels was, that one was a very hard enamel, practically insoluble in water,—practically none dissolved in the water when grinding—whereas the other dissolved somewhat in the grinding process. Why can I temper the soft enamel and not the hard one?

Mr. McDougal: This paper is, indeed, very interesting to any one connected with the casting of clay ware. The reactions and theory discussed in its text are fundamental to an understanding of some of the phenomena involved in the preparation of a clay or porcelain body or slip for use in the casting process. Owing to a lack of proper working knowledge of the use of soluble salts, or electrolytes, many have tried and condemned the casting process as a whole. Not only does a great deal depend upon the certain clay or body mixture used, and on the certain salt or combination of salts used, but with a given body and given salts, care and judgment must be exercised in properly proportioning salt to body.

A difference of one-twentieth of one percent (based on addition to dry body) of salt is sufficient to alter the condition of the colloids in some slips (by effecting a preponderance of either sol or gel) to such a degree as to ruin the possibility of successfully casting that slip.

That casting can be successfully done is evidenced by a paper in last year's Transactions by Mr. C. J. Kirk, in which he

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describes the casting of sanitary porcelain, where the intricacies of the shapes and the size of the pieces cast, furnish most severe tests whereby the safeness of the process could be judged.

Mr. Denmead: I wish to ask Mr. McDougal what thickness of mold is possible by the use of salts.

Mr. McDougal: In a "solid cast" piece, that is, where both surfaces of the piece are adjacent to a plaster mold surface, and where the mold is to be used once every day, I would say that about one and one-half inches would be the limit, with the average porcelain body. This limit would vary with each different body and with each different proportion of salt content.

Mr. Denmead: I asked that question, because we have entered the casting business and have been attempting to cast shells something like two inches in thickness at one operation. We found that, whenever the salts were used the shell would not retain its shape after an inch in thickness was reached. We were able to make the shells of practically any thickness in small sizes. When we worked with large sizes, and made a shell of more than two and a half feet high and a diameter of greater than ten inches, we found that there was something in the colloidal nature of the salts, which seemed to fill up the pores of the plaster and make absorption very slow. The shell would harden on the outside and prevent any more water from being absorbed, and as a final result the shell cracked every time. I want to get around such troubles, if possible, in a large thick piece.

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GLASS MISCELLANIES: NOTES.

BY ALEXANDER SILVERMAN

SIMILARITY BETWEEN AQUEOUS AND GLASS SOLUTIONS OF GOLD

Those chemists among you who have observed reactions taking place in aqueous solutions of gold salts have noticed that the molecular solution of the chloride is yellow; that on addition of potassium carbonate and formaldehyde, or a solution of yellow phosphorus in ether, a red colloidal solution of gold is obtained; and that on boiling with oxalic acid a brown precipitate and blue supernatant colloidal solution result.

All of these forms may be obtained in solid solution in glass, though different reagents are naturally employed to obtain the results. The specimens which I have brought as illustrations are lead-potassium-sodium silicate glass into which gold was introduced as chloride (the solution sprinkled on sand, which, after drying, was added to the batch). Stannous oxide served as reducing agent. The first specimen, exactly as drawn from the pot, is yellow and corresponds to the molecular solution in water. The second shows the red colloidal form produced by reheating the yellow compound. The third shows both brown precipitated gold and the blue colloidal solution in which particles are larger than in the red solution. The third type results from repeated heating of the red form. All three samples are from the same pot of glass.

EFFECTS OF VARIOUS TEMPERATURES ON COLORED GLASS

Having observed that certain colored glasses are very much darker at high temperatures that at ordinary room temperature, it occurred to the writer that there might be a further change at very low temperatures. Small specimens of various colored glasses were accordingly immersed in liquid air and results noted. Selenium ruby, which is black at high temperatures and ruby at

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ordinary temperatures, varies from yellow to orange in liquid air. With copper and gold ruby, the change is less marked. Cadmium yellow is lighter. No ordinary perceptible change takes place in blues and greens. That the change in color was due to the temperature and not to the medium, was clearly demonstrated, as the glass samples, when first removed, possessed the same color as in liquid air, and where changes had taken place at the low temperature, gradually came back to normal color.

Since marked changes had been observed in reds and yellows, other substances, such as potassium bichromate, sulphur, antimony sulphide, etc., were introduced into the liquid air. All became lighter in color except antimony sulphide, which darkened, and all again assumed the normal color on warming to ordinary room temperature.

Although these results are only qualitative because of the limited supply of liquid air available at the time, and difficulty in quantitatively analyzing color at the low temperature without special apparatus, the writer presents these preliminary notes and hopes to furnish more exact data later.

A CHROME RUBY GLASS

Considerable literature on chrome-pink glazes has appeared during recent years which has suggested to the writer the possibility of producing a chrome pink or ruby glass. As the result of a number of experiments performed, an interesting glass has been obtained, which though chrome green in single layers is ruby when light is transmitted by a double thickness, i. e., one piece superimposed upon the other. The position of surface seems to have no influence on color. A faint ruby is noticeable also in spots where a single layer is somewhat heavier. The phenomena may be observed in the two specimens exhibited, both of which are pieces of a sample ball, blown from the glass without reheating.

Dichroic effects have been observed in aqueous solutions of chromium salts and the changing color of the mineral alexandrite is familiar to many, but to the writer's knowledge, no such

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effect has previously been noted in connection with glass. It is hoped that the researches will ultimately result in a chrome-ruby glass.

Department of Chemistry,
University of Pittsburgh

DISCUSSION

Mr. Carder: Professor Silverman's article is very interesting and bears out facts that some glass makers have been aware of for some time. If I remember rightly Professor Barff drew attention to these phenomena in 1872.

The molecular changes produced by quickly heating gold ruby showing a muddy or brown tinge by reflected light and a bluish color by transmitted light is well known, and the glass maker endeavors to prevent this by heating slowly in the reducing atmosphere of a lehr or kiln, which insures what Professor Silverman calls the red colloidal form.

I have never seen or been able to produce brown precipitated gold and the blue colloidal solution in glass by repeated heatings after the red stage has been reached; on the other hand, it is produced always by quickly heating.

The effects of various temperatures on colored glass, especially low temperatures, is a new departure, and from a scientific point of view, of some importance, and I hope Professor Silverman will furnish more data.

I trust that Professor Silverman will continue his experiments on chrome ruby glasses.

I have been aware for some time that pink colors can be obtained by chrome in conjunction with other oxides in glass.

Colors ranging from a pale green to pink and purple are obtained by careful and numerous reheatings. Such colors are very fine, but it is with difficulty that two pieces can be obtained alike.

Mr. Frink: So far as Professor Silverman has progressed with his chrome ruby, there is little to be said in the nature of discussion.

There is one suggestion, however, which comes to my mind. I note that he speaks of changes in color produced by the vary-

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ing temperatures to which glass specimens were subjected, and his remark that these changes in color were due to temperature and not to the liquid air is undoubtedly true in a sense. There would be no change in color for temperature alone; at least temperatures below the glowing point are not visible. Is it not the size of the particles or the size of the molecules and their relative position in the various glasses and other materials mentioned which produces varying angles of light refringence and reflection, or perhaps alters the degree of absorption which again would change the length of light ray and in consequence its color? Of course, reds and all those colors at the red end of the spectrum will be changed to a greater extent than those at the violet end, for the wave length is longer, and any changes that are brought about by reason of molecular size in the specimen will naturally introduce a greater deviation of the incident ray, perhaps changing its phase or its length. One, both or all of these may be affected, depending upon the light-transmitting, absorbing or refracting properties of the substance.

It certainly will be interesting to learn Professor Silverman's later experiments and results with more elaborate apparatus. As a suggestion, sodium, argon or mercury lights with filtering devices transmitting light of known wave length might be tried so as to determine the effect of temperature on the color of glass as compared with its effects on the pure light rays.

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SOME OF THE PROPERTIES OF WHITE PORTLAND CEMENT

BY P. H. BATES, PITTSBURGH, PA.

The uses of a white Portland cement in competition with Keenes cement and other hard burned slow setting plasters, is sufficiently great to cause quite a demand for such a material. Some idea of the extent of this demand may be gained from the fact that in the Bankers Trust Building of New York 5000 barrels were used, largely for backing marble and stone "base boards," tile, etc. Its use as a stucco for outside wall finishing, either alone or with a tint, is also large.

At present, it is made by the manufacturer so as to pass the specifications covering the ordinary gray cement, and consequently its manufacture involves some slight difficulties — the principal one of which seems to be securing a material setting too quickly. This is caused not so much by the high alumina content alone, which is rather less than the gray cements, but by the absence of iron oxide. Contrary to the old idea, iron oxide does not act similarly to alumina and cannot replace it even in small quantities without materially affecting the cement, but in some unknown way it prevents the quick hydration and consequently causes slower set. There is no difficulty in reaching a temperature sufficiently high to produce satisfactory white clinker without the use of a flux. There is some trouble in securing a clay sufficiently low in iron oxide to give a satisfactory white color; and even now the white clays used by the manufacturers give a clinker which requires grinding to a finer degree, than that to which gray cements are ground, in order to obtain a good color. This, however, increases the troubles with the time of set, since the finer a cement is ground the quicker will it set.

In order to obtain first hand information in regard to this class of cements, the following series of burns were made; the clinker resulting from these was examined and tested as herein-

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after described. Particular attention was given to the regulation of the set by plaster and the determination of the effect of the addition of various quantities of plaster on the strength.

RAW MATERIALS AND PRODUCTION OF CLINKER

The raw materials used were a white clay, a potash feldspar, flint, partially calcined alumina and limestone. The analyses of these are:

	CLAY	FELDSPAR	FLINT	ALUMINA	LIMESTONE
SiO_2	77.20	70.83	98.38	1.44	0.08
Al_2O_3	15.94	16.60	0.44	96.02	0.12
Fe_2O_3	0.94	0.19		0.35	
CaO	0.50	0.44	....	0.37	55.40
MgO	1.14	0.08	....	0.35	0.79
Na_2O	....	3.29	....	....	....
K_2O	....	8.32	....	....	....
Ignition loss	3.65	0.63	0.27	1.56	43.57
	99.37	100.38	99.09	100.09	99.96

In the first three burns, the raw materials were clay and limestone to which a little of the feldspar was added. This was added in order to correct the mix as first made, which was desired to be similar to the mix used by one of the cement companies making white cement, and after the supply of white clay on hand had been exhausted. It was used in each of the three burns to the same extent and formed about one percent of the mix.

The fourth burn had for raw materials flint, alumina and limestone, and the fifth had feldspar and limestone only. As calculated, the first and second burns had the same lime content, but the first had a higher silica and lower alumina content than the second; the third burn has the same silica content as the second, the same alumina content as the first but a higher lime content than either. The first, fourth and fifth burns had the same composition—thus producing three cements of similar composition made from three different raw materials.

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The relation between the composition of these burns is more readily understood by the analyses of the clinker, which follows:

BURN NO.	1	2	3	4	5
SiO_2	26.19	24.04	23.38	25.94	26.31
Al_2O_3	5.97	7.35	6.03	6.55	6.30
Fe_2O_3	0.44	0.68	0.53	0.44	0.31
CaO	66.04	66.02	68.35	65.50	65.72
MgO	1.32	1.43	1.38	1.35	1.10
Na_2O	0.00	0.00	0.01	0.07	0.19
K_2O	0.24	0.15	0.14	0.12	0.32
Ignition loss	0.27	0.54	0.60	0.36	0.21
	100.47	100.21	100.42	100.33	100.46

The raw materials were ground in a ball mill until 85 percent passed a 200 mesh sieve. In the case of the feldspar, alumina and flint, it should be mentioned however that as purchased, 95.8 percent of the feldspar, 69.6 percent of the alumina and 98.8 percent of the flint passed this sieve. The fineness of the clay was not determined but was as received from the "bank," and required preliminary crushing in a jaw crusher.

The material, after grinding, was burned in a 2 ft. by 20 ft. rotary gas-fired kiln. This kiln was lined with magnesite brick (made from high iron magnesite), so that the clinker was contaminated a little by iron from this source, and the resulting clinker, excepting burns Nos. 4 and 5, was a little more of a cream color than the two domestic white cements now on the market, but still of such a degree of whiteness that it was necessary to compare them side by side with the commercial material before the inferiority in color was noticed. Burns Nos. 4 and 5 were a dead white.

No difficulty was experienced in making any of the burns excepting the high alumina burn No. 2. In this case, there was a decided tendency for the clinker to form "rings" in the kiln, thereby reducing the draft and consequently lowering the temperature. The knocking down of these rings necessitated the temporary shutting off of the gas, which further reduced the

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temperature. Before the kiln could be worked continuously after the removal of one of these rings it was necessary to raise the temperature while slowly turning over the kiln, entailing much extra labor and loss of output. The average temperature for each burn was:

Burn No. 1	1545°C.
Burn No. 2	1496°C.
Burn No. 3	1519°C.
Burn No. 4	1535°C.
Burn No. 5	1536°C.

Readings were made every 15 minutes over a period of 6-7 hours, with a Wanner pyrometer which was checked on several occasions during the burns to within 15° by a Holborn-Kurlbaum pyrometer.

The clinker as produced was of a light green color, about one-half inch in diameter. It was very well sintered but not vitrified, and would be considered well burned with but slight and infrequent appearances of underburning.

The petrographic analysis showed that in every case, the β orthosilicate of lime was the most important constituent, though the tricalcium silicate was present in considerable amounts; the only aluminate present was the tricalcium aluminate; there was a little low refracting colorless glass present; free lime was present in every case, but in burn No. 4 to such a slight extent that White's test was negative (production of lime phenolate in a nitrobenzol solution of phenol by the free lime). The petrographic examination also showed that burn No. 1 contained a little more free lime than No. 4, burn No. 2 more than burn No. 1 and burn No. 3 the most. This was later borne out by the constancy of volume tests. (See Table I).

PRODUCTION OF CEMENT FROM THE CLINKER

The clinker, amounting to about 275 pounds, was crushed in a jaw crusher, then passed through rolls until all passed a 20 mesh sieve, and then ground in a ball mill with flint pebbles until about 82 percent passed a 200 mesh sieve. It was then di-

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vided into five portions, one portion was tested without the addition of plaster; a second portion was tested after grinding for a short while in a ball mill with approximately 1 percent plaster; another after the addition of 2 percent; another after the addition of 3 percent, and the last after the addition of approximately 4 percent. An actual determination showed these different portions of the different burns to contain the following amounts of SO_3:

PORTION NO.	2	3	4	5
Burn No. 1	0.57	1.32	1.63	2.31
Burn No. 2	0.61	1.17	1.58	2.27
Burn No. 3	0.53	1.11	1.68	2.34
Burn No. 4	0.55	1.08	1.57	2.26
Burn No. 5	0.59	1.05	1.53	2.31

The fineness of the different burns on the 100 and 200 mesh sieves was as follows:

	PASSING	
	100 MESH *percent*	200 MESH *percent*
Burn No. 1	98.2	82.7
Burn No. 2	98.0	84.2
Burn No. 3	97.6	83.6
Burn No. 4	99.0	84.4
Burn No. 5	98.3	83.4

The specific gravity of the various portions of each burn was:

	PERCENT PLASTER				
	0	1	2	3	4
Burn No. 1	3.188	3.182	3.181	3.171	3.152
Burn No. 2	3.158	3.155	3.155	3.154	3.114
Burn No. 3	3.167	3.150	3.146	3.138	3.124
Burn No. 4	3.173	3.171	3.171	3.156	3.142
Burn No. 5	3.183	3.181	3.174	3.171	3.154

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It will be noticed from these that the gravity is very little lower than that of the ordinary cements, and still above the low limit of 3.10 placed in specifications for material of the latter class.

TIME OF SET

As stated before, the primary reason for making the investigation was to determine the effect of the addition of sulphate of lime upon the setting time of the cement. It has been gener-

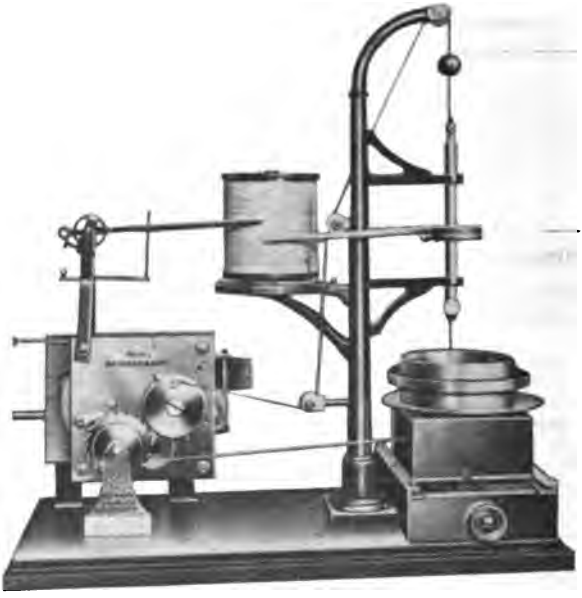

FIG. 1

ally believed that white cements require more SO_3 to produce a satisfactory set than the ordinary gray cements, and it has been suggested that the limit of 1.75 percent for this constituent, as adopted by the various American engineering societies, be increased by from .25 to .50 percent. In this particular investigation plaster of Paris was used. Undoubtedly the use of gypsum would have given different results since in grinding the cement with this form of the sulphate, sufficient heat is generated to liberate at least one molecule of water, which in the closed ball

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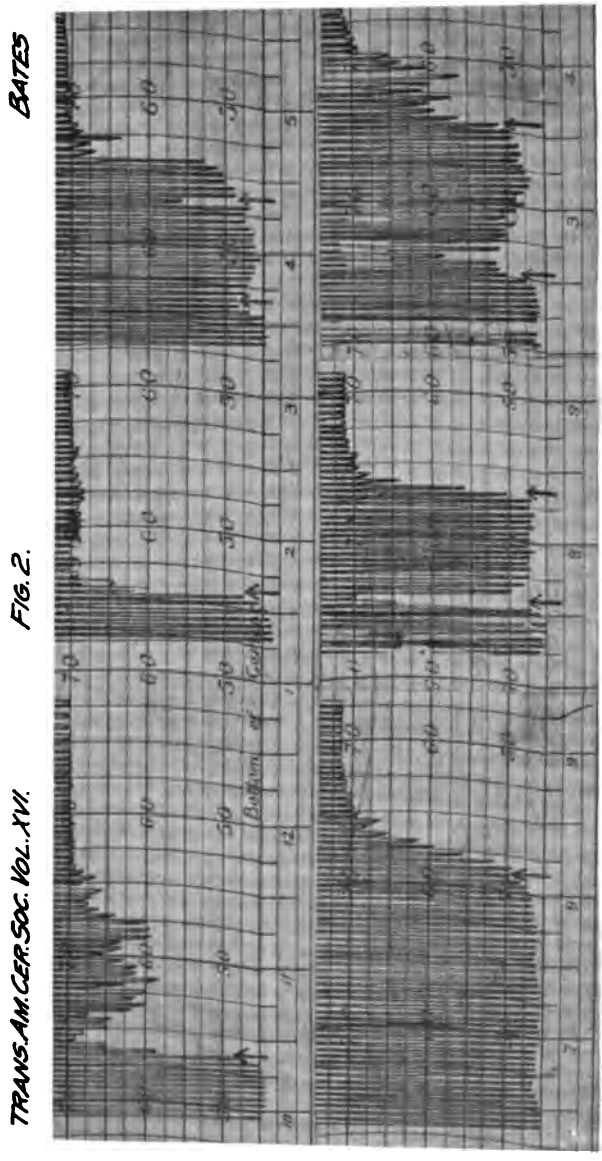

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mill, combines first with any free lime and then with the calcium aluminate; this combination would undoubtedly produce a slower set when the addition of a definite amount was made, than if an amount of plaster containing the equivalent of SO_3 content was added.

An examination of Table I which gives the time of set as determined both by the Gilmore and Vicat needles, would indicate that, with one exception, the content of approximately 1.75 percent SO_3 (3 percent $CaSO_4$) was already too great to produce satisfactory results. This is seen in all instances, except burn No. 4, when the addition of approximately 2 percent $CaSO_4$ produces the quickest final setting material. While this table also shows that so far as constancy of volume is concerned, this burn is more satisfactory than three of the others, yet it is no better than burn No. 1, to which it is similar in composition. It is a somewhat better cement than burn No. 1 so far as the strength of mortar and concrete which it produced are concerned, and from the petrographic analysis it also showed less free CaO, but there is no satisfactory reason why increasing amounts of SO_3 produce so little change. This fact, however, makes it necessary to do further work before any positive statement can be made in regard to the proper amounts of SO_3 to be used in regulating the set of this kind of cement.

The purpose of burn No. 2 was to see the effect of increasing the percentage of alumina on the time of set. Owing to the difficulties mentioned in making this burn, a rather poor material containing much free lime was obtained. It does not seem that the increase of approximately 1.25 percent Al_2O_3 has materially increased the time of set.

It has been noticed by several observers[1] that some time after the initial set has been passed, the cement seems to become more plastic again. In the present investigation a recording Vicat needle (Nicol spissograph) was used, the working of which is shown sufficiently clearly in Figure 1, making further description unnecessary. It was soon found that this phenomenon could

[1] McKenna, *Metallurgical and Chem. Eng.*, Vol. 2, 1912, 83; Burchartz, *Ton. Zeitung*, 1910, and *Eng. Record*, 1909, 661; Gary, *Concrete and Constructional Engineering*, 1906, 356.

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TABLE I

SHOWING TIME OF SET, NORMAL CONSISTENCY AND CONSTANCY OF VOLUME

BURN NO.	APPROXIMATE PERCENT OF $CaSO_4$ ADDED	NORMAL CONSISTENCY	SET								PATS.			
			GILMORE				VICAT.				28 DAYS IN AIR	28 DAYS IN WATER	24 HOURS IN DAMP CLOSET THEN BOILED	24 HOURS IN DAMP CLOSET THEN STEAMED
			INITIAL		FINAL		INITIAL		FINAL					
			H	M	H	M	H	M	H	M				
1	0.0	20.5	0	10	7	20	0	05	6	30	OK	OK	OK	OK
	1.0	20.5	0	15	5	35	0	09	1	40	OK	OK	OK	OK
	2.0	20.0	2	55	4	55	2	30	4	35	OK	OK	OK	OK
	3.0	19.0	0	47	6	30	0	27	5	50	OK	OK	OK	OK
	4.0	19.0	0	34	4	45	0	25	4	25	OK	OK	OK	OK
2	0.0	22.5	0	09	2	35	0	05	0	55	Soft:C[1]	OK	D	D
	1.0	22.0	0	05	0	33	0	06	0	15	OK	OK	D	D
	2.0	22.0	1	50	3	05	1	48	2	10	OK	OK	D	D
	3.0	21.0	2	05	6	00	0	50	5	20	OK	OK	D	D
	4.0	21.0	0	35	5	10	0	30	4	55	OK	OK	D	Soft:W[2]
3	0.0	22.5	0	20	9	00	0	06	4	30	Soft:W	Soft:W	D	D
	1.0	22.5	0	33	2	35	0	26	0	45	Soft	W	D	D
	2.0	21.5	2	40	6	50	2	00	5	00	Soft:W	OK	D	D
	3.0	21.5	0	47	5	10	0	21	4	30	Soft:W	OK	D	D
	4.0	21.5	0	44	4	45	0	37	4	15	Soft:C	W & C	D	Soft:Checked
4	0.0	23.5	0	06	5	30	0	02	3	30	OK	OK	OK	OK
	1.0	23.5	0	18	5	35	0	10	1	45	OK	OK	OK	OK
	2.0	22.5	0	33	0	48	0	23	0	35	OK	OK	OK	OK
	3.0	20.5	0	33	3	00	0	50	4	15	OK	OK	OK	OK
	4.0	19.5	0	42	5	20	0	30	4	45	OK	OK	OK	OK
5	0.0	21.5	0	12	5	30	0	09	4	35	OK	OK	D	Soft:Checked
	1.0	21.5	0	04	0	30	0	03	0	22	OK	OK	D	Soft:Checked
	2.0	20.0	1	55	4	00	1	40	3	25	OK	OK	D	Soft:Checked
	3.0	19.5	0	35	4	05	0	30	4	00	OK	OK	D	Soft:Checked
	4.0	19.5	0	39	3	30	0	32	3	05	OK	W & C	D	Soft:Checked

[1] Cracked. [2] Warped.

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be detected by this apparatus, and in Figure 2 some of the curves as obtained by this instrument show this condition. This condition could not be always detected by the instrument, though using the same cement, nor are the curves similar. Thus it is seen in the figure that the first and third curves of the top row (burn No. 3 containing 3 percent $CaSO_4$) both show this condition, but the needles penetrated much further in the third, after the initial set—really giving two initial sets almost 50 minutes apart; while the second does not show this at all. The second and third curves of the bottom row also show this phenomenon; both give two initial sets, while the first shows a slight tendency towards this, but the needle penetrated a little too far at the early period to show a set. This cement (burn No. 2 containing 3 percent $CaSO_4$) gave very different initial sets as determined by the Gilmore and Vicat needles (see Table I), and further work, using this cement and the two needles, showed that the time as determined by the Gilmore needle corresponded to the second initial set as noted by the Vicat, the Gilmore needle not being sufficiently delicate to detect this—excepting in one case when an initial set of 48 minutes was obtained, agreeing very closely with the 50 minutes obtained by the Vicat. The first curve of the bottom row which does not show an initial set at 50 minutes, but only one at two hours, agrees with that given by the Gilmore needle of 2.05 hours. As the temperature of the cement, mixing water and room, did not differ by more than two degrees, the difference in the curves cannot readily be explained by temperature difference. The cement and water were mixed in each case by the same operator for the same length of time.

The reason for this increased plasticity has been explained by McKenna, as due to a disengagement of water when some compound resulting from the hydration, separates from the supersaturated solution. The water thus freed acts upon the colloidal material of hydration and softens it. Further hydration, of course, again takes up this water and the setting proceeds.

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CONSTANCY OF VOLUME AND NORMAL CONSISTENCY

Table I also shows the condition of pats after storing, in air, in water for 28 days, and after boiling and steaming at the end of 24 hours. It is seen that burns Nos. 1 and 4 are satisfactory in every respect, and burns Nos. 2 and 5 are satisfactory except after the "boiling" and "steaming," while burn No. 3 (containing the highest percentage of lime and the lowest percentage of silica and alumina) is almost entirely unsatisfactory. These results agree entirely with the petrographic examination. The latter method of examination of a clinker or ground cement to determine the relative amount of free lime is much more quickly made than the boiling or steam test, and with some little practice it is comparatively easy to predict the degree of soundness. As burns Nos. 4 and 5 were made at the same temperature, at the same rate of feeding of the raw material, and of the same degree of fineness and same speed of revolution of kiln, it would appear as if a higher temperature were required for the lime to combine with the silica and alumina of the feldspar, than with free silica and alumina which were used in burn No. 4.

This table also shows the well known fact that with increasing amount of sulphate, a decreasing amount of water is required to produce paste of the same consistency.

STRENGTH TESTS

Specimens of neat cement and 1:3 standard Ottawa sand were made for tension tests; 2 in. cubes of 1:3 standard sand were made for compression tests; and 6 in. 1:1½:4½ concrete cubes were made, of the portion of each burn containing 1 and 3 percent plaster, also for compressive strength.

The average strength of three specimens as made above for each portion of each burn after 24 hours, 7, 28, 90 and 180 days, is given in Table II, and shown graphically in Figures 3, 4, 5, and 6.

These results do not follow those obtained for the time of set, namely: that the portion containing 2 percent plaster gives the most desirable material. In the greater number of cases the

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TABLE II

SHOWING TENSILE STRENGTH OF NEAT AND 1:3 SAND BRIQUETTES AND COMPRESSIVE STRENGTH OF 2 IN. 1:3 SAND CUBES AND 6 IN. 1:1½:4½ CONCRETE CUBES.

Batch No.	Plaster, approximate percent	Neat specimens					Sand specimens					Sand specimens				Concrete specimens		
		Tensile strength at end of					Tensile strength at end of					Compressive strength at end of				Compression strength at end of		
		24 hours	7 days	28 days	90 days	180 days	24 hours	7 days	28 days	90 days	180 days	7 days	28 days	90 days	180 days	28 days	90 days	180 days
1	0	226	392	704	676	608	92	212	376	361	463	1232	2355	2769	3400	....	....	....
	1	238	427	570	647	613	111	205	378	417	493	1389	2117	2927	3171	1279	1999	1976
	2	258	505	700	754	622	151	224	371	420	485	1191	2034	3209	3538	....	....	....
	3	370	690	783	798	989	172	278	377	423	437	1666	2775	3518	3888	2272	3250	3202
	4	293	640	629	809	831	62	248	348	410	470	1775	2890	3482	3799	....	....	....
2	0	214	410	508	446	423	106	171	312	387	508	1129	1335	2520	2690	....	....	....
	1	279	415	480	405	473	119	168	296	384	455	968	1541	2304	2828	1203	1749	1986
	2	299	382	568	570	570	155	163	356	434	505	1402	2374	3188	3210	....	....	....
	3	360	512	565	644	722	169	181	369	441	487	1520	2167	4192	4086	1897	2850	3051
	4	158	587	645	619	794	41	184	334	333	419	1339	2113	3140	3527	....	....	....
3	0	209	248	Enlarged	Enlarged	Enlarged	49	123	93	128[1]	269	692	749	1497	1682	....	....	....
	1	256	172	Enlarged	Enlarged	Enlarged	86	94	21	108[1]	140	798	395	830	1139	1175[1]	1603[1]	910[1]
	2	330	346	607	567	535	110	134	278	363	368	1066	1682	2497	2996	....	....	....
	3	321	477	637	657	623	74	121	336	360	352	1243	1479	2287	2872	2390	3135	3315
	4	124	254	Enlarged	467[1]	507	31	107	174	208	252	753	1420	2128	2158	....	....	....

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	0	273	442	502	603	478	204	265	402	425	377	1608	2242	2862	3342	....	....	....
	1	317	392	421	528	549	130	241	334	397	422	1616	2047	3558	3427	1492	2626	2195
4	2	290	504	451	549	614	177	258	351	389	426	1812	2298	3435	3479	....	....	....
	3	342	621	646	771	716	237	308	410	500	518	2097	2392	4333	4384	2466	3321	3564
	4	362	777	709	830	747	138	262	475	396	576	1793	3408	3873	4660	....	....	....
	0	232	406	514	489	442	108	160	272	360	504	1022	1638	2573	3271	....	....	....
	1	276	394	350	496	507	117	131	294	401	484	998	1714	2718	3162	1542	2132	2480
5	2	351	536	580	629	578	137	160	331	406	490	1165	2213	2750	3113	....	....	....
	3	356	575	702	747	635	153	178	338	380	465	1233	2316	2848	3481	2031	3153	3530
	4	123	488	474	459	558	26	153	295	333	404	924	1482	2712	3188	....	....	....

[1] Much enlarged.

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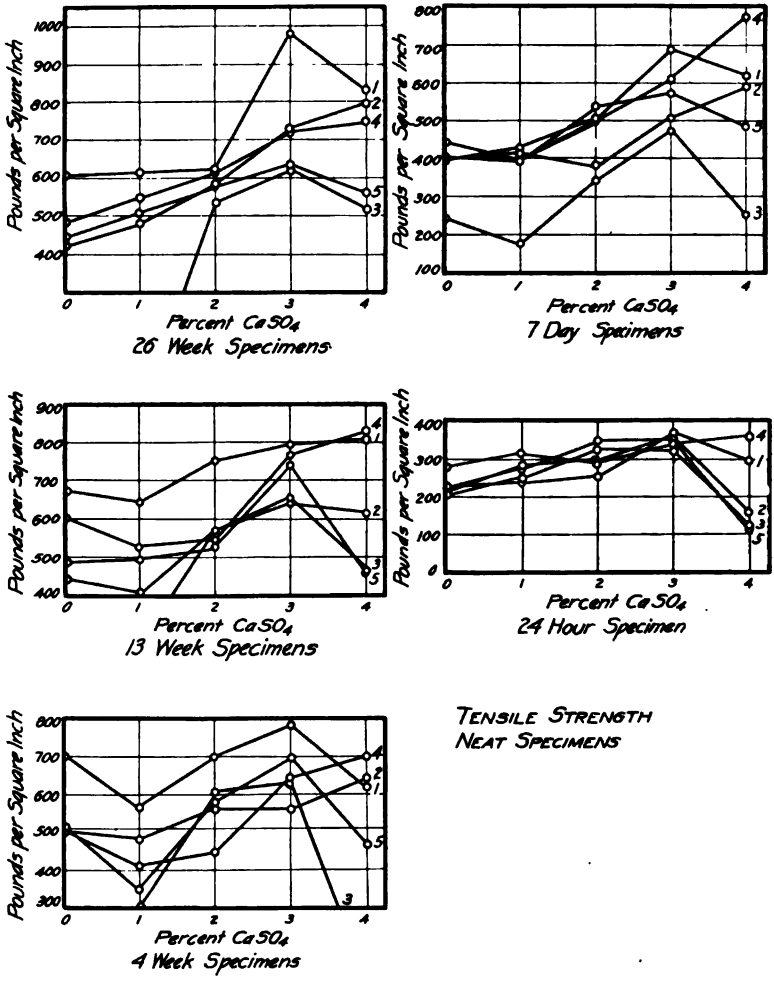
TRANS. AM. CER. SOC. VOL. XVI FIG. 3 BATES



TENSILE STRENGTH
NEAT SPECIMENS

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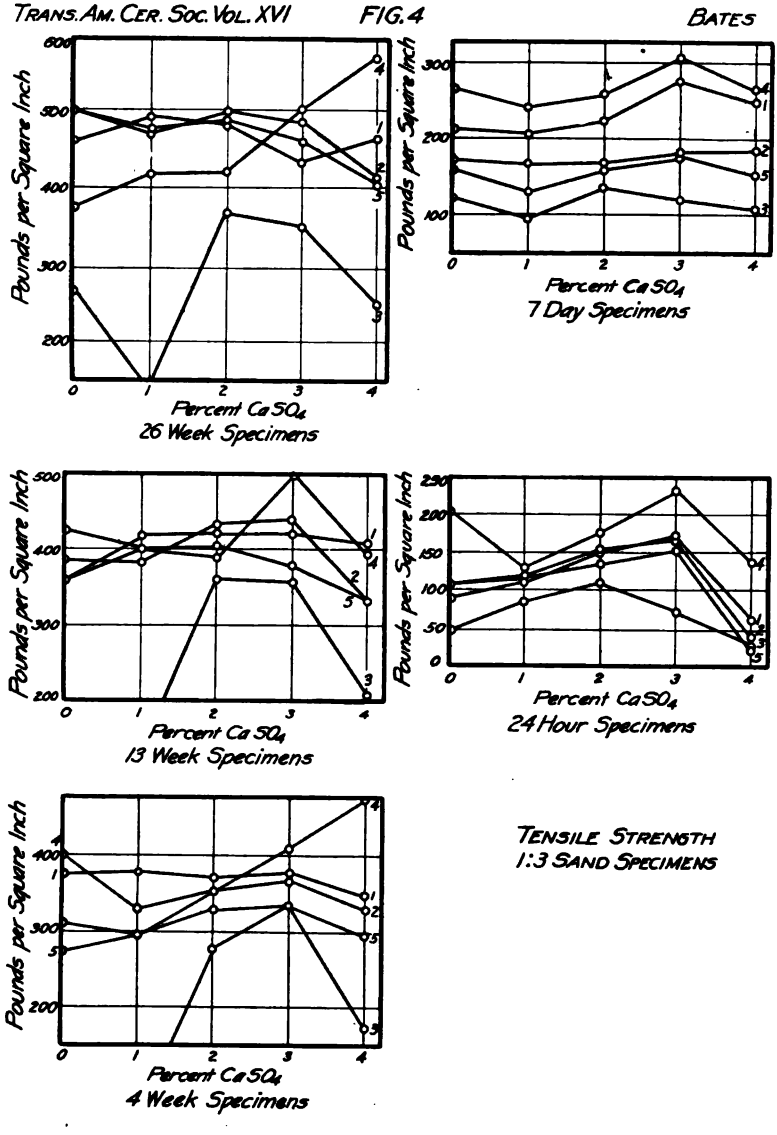

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addition of 3 percent seems to give the best results, though in some cases 4 percent gives the best. Also the same percentage may give different relative strengths at different periods as in burn No. 4 when both the sand tension and compression specimens, containing 4 percent plaster, give a higher figure at four weeks than those containing 3 percent; while at the end of one week, those containing 3 percent gave the higher strengths.

It is also noticed that these tests roughly follow the constancy of volume tests—those cements which gave pats showing a poor "boil" or "steam" also show poor strengths. This is particularly shown in burn No. 3, where the pats containing 1 percent plaster show a retrogression in strength of the neat specimens between the 24 hour and 7 day specimens, and at the end of the 28 day period had enlarged so much that it could not be placed in the testing machine. The portion containing 2 percent gave 607 pounds per square inch at 28 days, while this same portion as a 1:3 sand tension specimen gave 278 pounds per square inch, and as a 1:3 sand compression specimen gave 1682 pounds per square inch at 28 days. The portion containing 1 percent gave but 21 pounds and 395 pounds per square inch, respectively. Note also the difference between the strengths of the concrete made from the cement of this burn containing 1 percent and 3 percent plaster, the former at 28 days showing signs of disintegration. The low strengths developed by the portions of burn No. 3 containing 0.0 percent, 1 percent and 4 percent plaster can all be explained by the fact that the lack of, or too low, or too great percentages of plaster allow the rapid hydration of the aluminate and trisilicate which produces the early strengths, simultaneous with the hydration of the free lime, the result being a breaking up of the bond of the particles. Whereas the proper amount of plaster holds back the hydration of the silicate and aluminate until after the lime is hydrated, thus not breaking up the bond, which in this case is subsequently formed.

The strength of the sand specimens are exceptionally good, if we take as a criterion the strengths desired by standard specifications (500 lbs. and 600 lbs. per square inch at the end of 7

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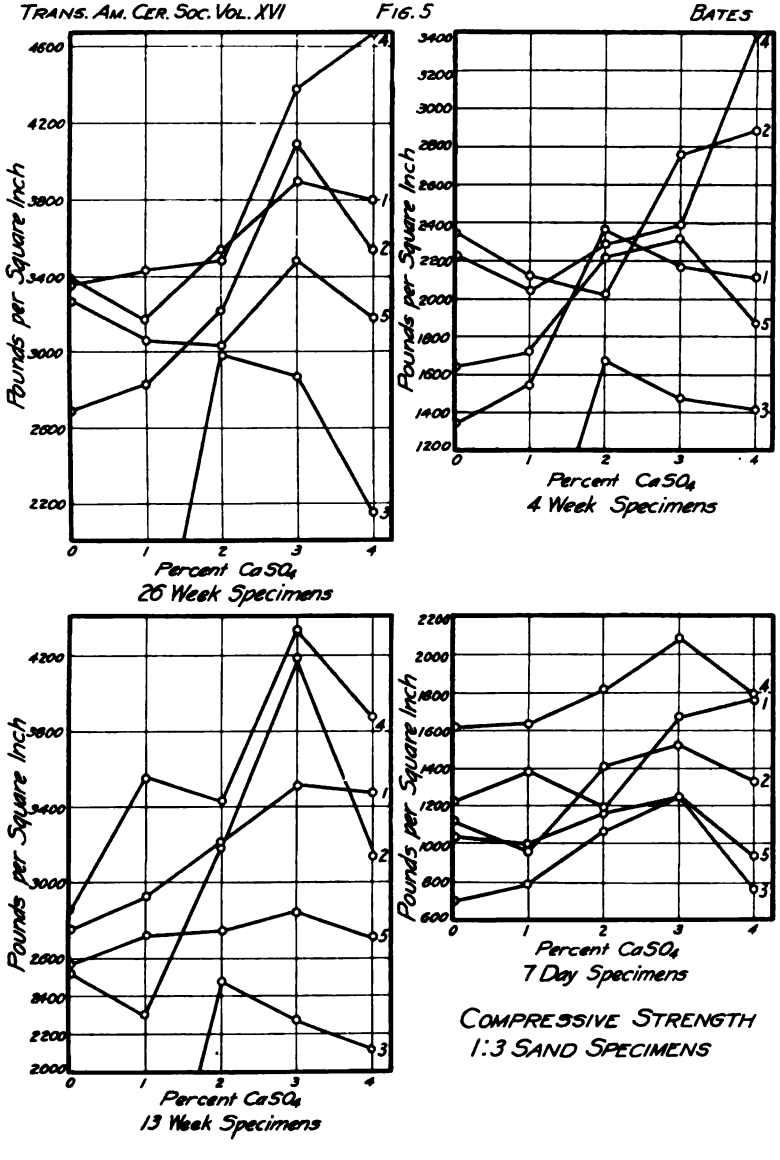

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and 28 days, respectively, for neat specimens, and 200 and 275 lbs. at the end of the same periods for sand specimens). In fact, it is clearly seen that there is no difficulty of producing a satisfactory cement comparable with the ordinary cement, when the proper addition of sulphate of lime has been made. That 1 percent was undoubtedly not the proper amount is shown by the strengths of the concrete, which in every case gave markedly better results when 3 percent was added, in one case a 100 percent better result being obtained and the least increase being a little over 25 percent. Whether further additions would have given still better results is not known, but it did not always do so in the case of the sand cubes.

The strengths developed by the cement from burns Nos. 1, 4, and 5 show clearly that the cement obtained from the flint, alumina and limestone give better results than that obtained from the clay and limestone, and the latter give better results than that obtained from the feldspar and limestone. Apparently, notwithstanding the temperatures of burning (which differed only 10°C) and the appearance of the clinker, burn No. 4 was properly burned, whereas burn No. 1 was not quite sufficiently burned, and burn No. 5 was underburned. This is borne out by the petrographic analysis and constancy of volume test as shown above. However, the strengths of all specimens (except the sand compression) made from the cement containing 3 percent plaster lie comparatively close together. But the results from these burns are far from confirming the statement that cements of similar composition will have similar physical properties, regardless of the nature of the raw materials from which they are made, though they do tend towards confirming it. Undoubtedly raw materials of a different composition will require different temperatures and different lengths of burning to produce equilibrium, but when once equilibrium has been reached, it is difficult to see how the same compound can have different physical properties. It must be remembered, however, that in the rotary kiln equilibrium has not been attained. A series of burnings in a down draft kiln is now under way, wherein these three raw mixes will be burned at the same time at various

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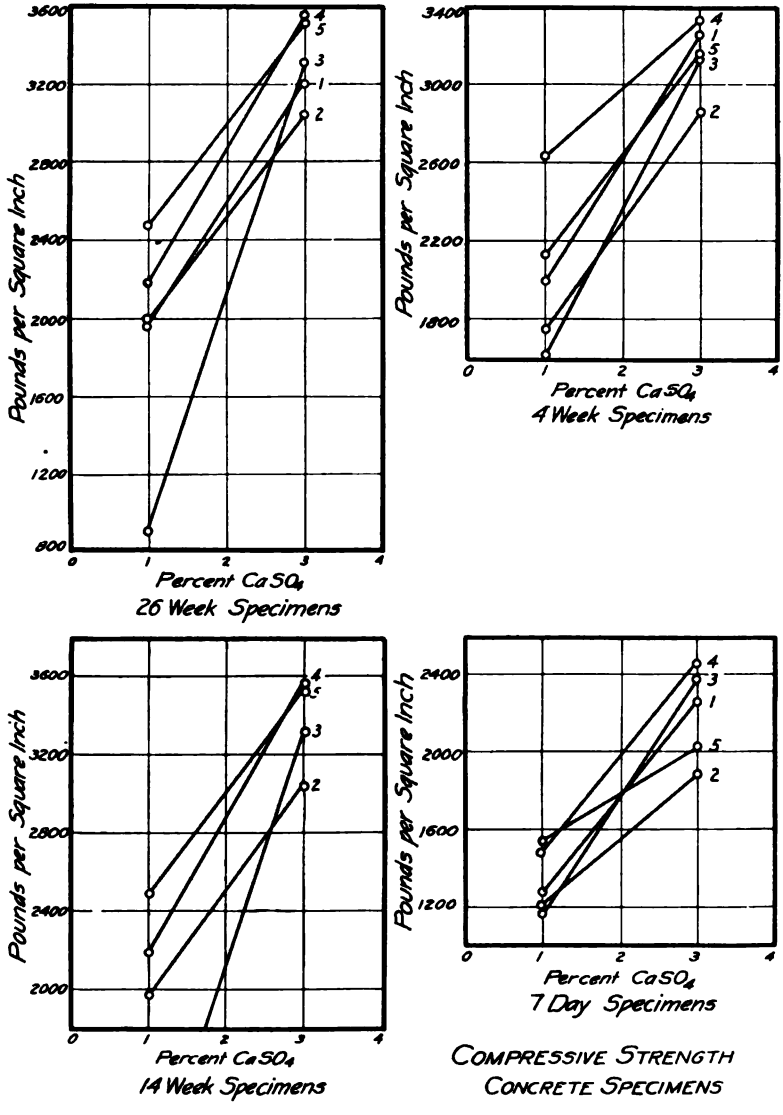
TRANS. AM. CER. SOC. VOL. XVI FIG. 6 BATES.



COMPRESSIVE STRENGTH
CONCRETE SPECIMENS

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temperatures. By examining the three clinkers produced at any one temperature, it is hoped to be able to gain some idea of the difference, if any, between them, and consequently to see at what temperature each must be burned to produce an identical cement.

SUMMARY

White Portland cement can be readily produced in a rotary kiln at a temperature but little above that used for burning ordinary cement. The material so produced has a higher silica and lower alumina content than ordinary cement, the lime being about the same.

A lower alumina content than in gray cement is necessary, since while it was not shown that high alumina makes very rapid setting cement, yet the temperature of softening is materially reduced with such increase, and the clinker "rings up" the kiln.

A high silica content is necessary, since with the already low alumina a very high lime content would otherwise result with consequent difficulty of reaching a temperature high enough to produce a sound cement.

While approximately 2 percent of sulphate of lime produced the best time of set, yet this amount did not produce the best strength. Since 3 percent and even 4 percent produced better strength it would seem necessary, if the best strength were wanted, to use the higher percentage of plaster and the consequent quicker setting cement.

Specimens have been made up which will be tested as late as at the end of three years. Consequently some of the remarks made above may require later modification.

Acknowledgements are due to Mr. E. R. Gates for superintending the making and testing of all specimens, and to Mr. A. A. Klein for the petrographic analyses.

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THE VISCOSITY OF SOME SHALES AT FURNACE TEMPERATURES[1]

BY G. H. BROWN

In the burning of building and paving brick molded from shales, the viscosity of the material during the vitrification period is of importance. A shale or clay which retains a relatively high viscosity during its vitrification may be more safely burned to a low porosity than one whose viscosity during this period of the burning is low. Clays of low viscosity produce kiln-marked ware when the vitrification period is carried too far. Obviously, the kiln marking is most pronounced in the bottoms of down-draft kilns, where the ware is subjected to the greatest load. Low viscosity is also coincident with rapid vitrification, since the rate of the latter is to a large extent governed by this factor. On the other hand, a certain minimum viscosity is necessary in order to make vitrification possible, and hence both limits must be considered. A comparison of the viscosities of seven typical shales used in the manufacture of paving brick and whose behavior during burning was known in a general way was made, two of the shales being from Illinois, one from Kansas, three from Ohio and one from West Virginia.

Test Pieces. The shales were tested in tension, the method being similar to that used by Bleininger and Teetor in comparing the viscosity of porcelain bodies. Test pieces eight inches in length, approximately one square inch in cross section and having the general form of briquettes used for cement testing, were prepared by pressing into plaster molds. The test pieces were burned to 850°C. before testing.

Method of Testing. The samples were burned in a gas fired test kiln, the temperature being measured by thermocouples and a recording galvanometer. For each burn, the furnace temperature was increased at the rate of 30° per hour above 700°C.

[1] By permission of the Director of the Bureau of Standards.

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The test pieces were suspended vertically from fire clay grids, the loads being applied by hanging to the lower ends fire clay weights of a size to subject the pieces to a tension of five pounds per square inch of the cross sectional area. Reference marks four inches apart were made in each piece for the measurement of shrinkage and elongation.

Seven burns were made, the finishing temperatures being respectively 1020°, 1050°, 1090°, 1110°, 1130°, 1150° and 1170°C.

Deformation versus temperature curves are shown in Figure 1.

A striking difference in the viscosities of the shales with progress in vitrification is evident.

Shale No. 1 from Kansas, we know to be a difficult one to burn to vitrification in commercial kilns. The viscosity is rapidly lowered with a relatively small temperature increase, and care must be exercised in burning to avoid excessive kiln marking and ruined ware.

Shales Nos. 2 and 3 from Illinois, although maintaining a high viscosity over a longer temperature range than does shale No. 1, show an abrupt lowering in viscosity at temperatures between 1090 and 1100°C. The two shales are very susceptible to kiln marking, and the temperature at which the viscosity is suddenly lowered must be avoided.

A more gradual change in viscosity with temperature increase is shown by the curves of shales Nos. 4 and 5. From tests made in the laboratory and from what is known of their behavior in commercial kilns, neither of these shales offers serious difficulty in burning to vitrification.

Shales Nos. 6 and 7 show a gradual lowering in viscosity with increase of vitrification, and in this respect are admirably adapted to burning with safety in commercial kilns. Paving blocks of high quality have been made in the laboratory from No. 6, while No. 7 is used commercially in the manufacture of paving brick.

Conclusions. As a general rule, a shale or clay maintaining a high viscosity with progress in vitrification, is to be pre-

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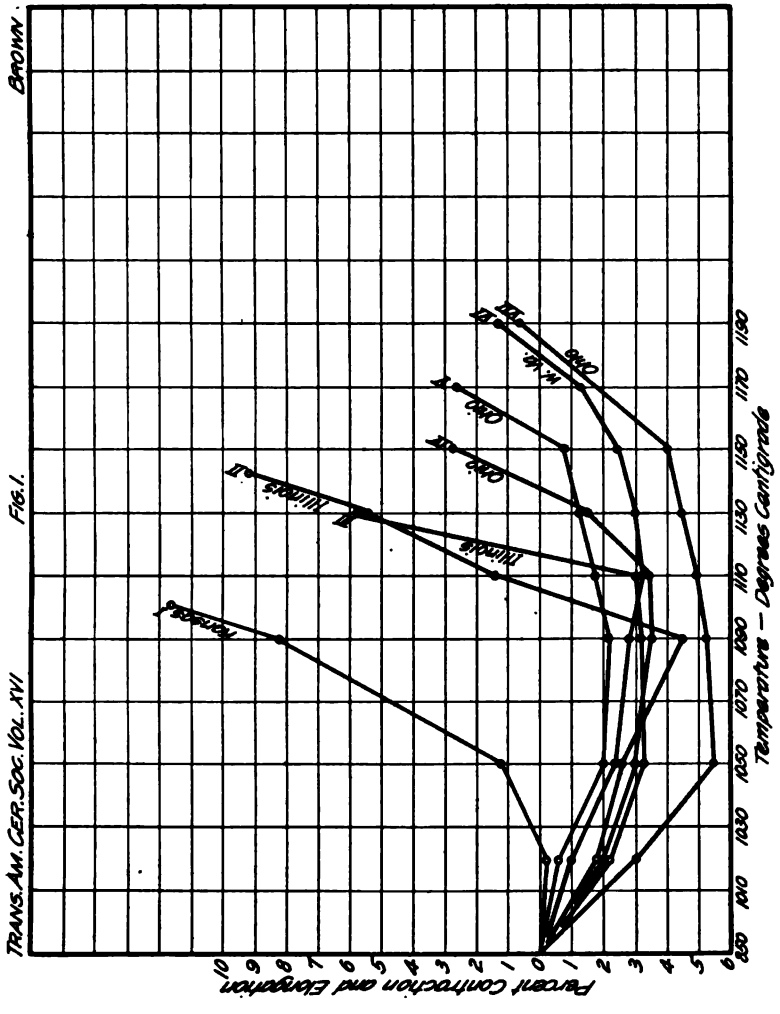

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ferred to one which is subject to sudden lowering of viscosity. An exception must be made, however, with very siliceous shales and clays which are apt to maintain a high viscosity throughout their vitrification and at the same time produce a product of inferior strength and toughness.

Singularly, from the limited number of tests made, the Illinois shales appear to be more subject to abrupt changes in viscosity than are the Ohio and Eastern shales. From what we know of the behavior of the shales of the respective states, this difference in behavior appears to be more or less typical.

A test of this kind is suggested as being of value in the testing of shales and clay as to their suitability for the manufacture of vitrified brick.

DISCUSSION

Mr. Karzen: As I understand the term viscosity, I think what is meant is a short vitrification length. The first shale, Mr. Brown had, will burn safely to 1010° and then take a sudden turn. He called it a short viscosity. I do not quite understand that. I think that the shale becomes more viscous and has a tendency to deform. That is what we call a short viscosity. I believe he was a little mixed up in these terms, or else I am. The shale that he called one with a short viscosity is more viscous because it has a tendency to soften up and go down under stress. I had such an experience with a shale from Michigan, and I think that in most cases a short viscosity is due to lime. I believe that the first three shales show all the earmarks of a high-lime shale.

Mr. Bleininger: Viscosity means in this case a certain degree of softening; but it is not necessarily coincident with vitrification because, in some cases, you may have vitrification and still have high viscosity. The point made by Mr. Karzen is not *apropos*. His conception of viscosity is not the property as usually understood in physics.

Mr. Watts: Do you not confuse viscosity and fluidity? High fluidity means low viscosity and *vice versa*. Not exactly

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fluidity, but as the expression fluidity is understood generally. The two terms are not synonymous.

Mr. Brown: We use the term viscosity in its physical sense, and not in the popular conception of its meaning.

Mr. Potts: I wish to make a remark of the same character as that of Mr. Watts. Viscosity is a property of fluids or liquids. Water is a liquid of low viscosity, glass a liquid of high viscosity.

Mr. Lovejoy: If we start with a liquid and finish up with a solid there will be a decrease in viscosity; but in testing clays we start with a solid and gradually soften it by progressive fusion, and viscosity increases.

Mr. Potts: A liquid that flows poorly has a high viscosity, and a liquid that flows easily has a low viscosity.

Mr. Landrum: We measure the viscosity of an enamel by the time it takes the enamel, at a certain temperature, to run out a hole in the bottom of the crucible. The least viscous enamel will run out in a shorter time than the others.

Mr. Doe: Do I understand that these bars had a weight attached to them and that when the curve falls below the zero line, the contraction of the bar actually lifted the weight?

Mr. Brown: Yes.

Mr. Doe: You spoke of viscosity at that stage, and I wondered where the viscosity came in.

Mr. Brown: The length decreased, and the shrinkage increased somewhat until we got past a point where the weight was sufficient to overcome the shrinkage.

Mr. Doe: The drop was due to viscosity, and you would not have the shrinkage after the curve started to rise?

Mr. Brown: Yes; somewhere in that neighborhood.

Mr. Lovejoy: Do I understand that the zero line showed shrinkage?

Mr. Brown: Yes.

Mr. Lovejoy: Then this is not what we ordinarily understand as viscosity. We develop these curves a great deal; and at the point where the curve reverses, shrinkage ceases and

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swelling begins. Our curves are shrinkage curves and bear no relation to viscosity.

Mr. Parmelee: There is a practical test, introduced into this country apparently from England, that has been found to be of value in testing body mixtures for sanitary ware. A lump of the mixture in the plastic condition is batted out to a thickness of three-eighths of an inch and cut or pressed into a mold to make a form similar to that of an hour glass having a length of nine inches and a width at the waist or narrowest portion of one inch, and three inches for the maximum widths of the ends. When dry and ready for burning, the trial piece is laid upon a flat tile and equal weights of approximately eighteen pounds each are laid upon both ends. After burning, the shrinkage and the presence or absence of signs of tearing or breaking at the waist are noted. This is a test of viscosity and tensile strength.

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FLUORIDES AS OPACIFIERS

BY J. B. SHAW, PITTSBURGH, PA.

In presenting this subject before the Society for discussion, the writer makes no pretense to any special knowledge of the subject, but on the other hand, freely admits that the object of the paper is to learn what others know about the subject.

Fluorides have been used as opacifiers in glass and enamels for many years and very excellent results have been obtained by their use, but the writer knows of no case where they have been successfully used for making opaque glazes. There are a great many places in the ceramic industry where an opaque glaze, properly controlled, would mean a great saving and improvement in the ware. The writer believes, if the action of fluorides was properly understood, that they would be the cheapest and most effective opacifiers we have for glasses, glazes and enamels.

There have been a great many theories advanced as to the action of fluorides in silicate fusions, among which might be mentioned the following:

1. The opacity is produced by silicon fluoride gas, SiF_4, which goes into solution in the glass when hot and is precipitated out and held in suspension when the glass cools.

2. The opacity is caused by SiF_4, not by the gas in itself, but by some characteristic crystalline structure which the glass is caused to assume by the SiF_4.

3. Opacity is caused by the formation of sodium-silicofluoride, Na_2SiF_6.

4. Opacity is due to precipitation of Al_2F_6. In *Dingler's Polytechnic Journal,* 1885, Weinreb states that alumina and fluorine are both essential in producing opacity with fluorides.

5. Opacity is due to precipitation of alumina, Al_2O_3, all F being evolved as SiF_4.

The writer has knowledge of opaque glass having been made with fluorides in absence of any Al_2O_3 except what might

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have been present as impurity in some of the raw materials, in which case, if present at all, it was in an insignificant amount.

In the face of such a diversity of opinion one is led to believe that fluorides act quite differently in different glass batches. It is a well-known fact that different heat treatment will greatly modify the result produced with any given fluoride batch.

The object of this paper is to show the lack of absolute knowledge of the action of fluorides, to stimulate a discussion of the subject and bring to light what is now known and encourage research in the future.

The only reason fluorides are not more extensively used is because they are not understood. A few questions are here asked, the answers to which would throw considerable light upon the subject:

1. In opaque fluoride glasses, is the ultimate composition of the opacifying material always the same or does it differ in different mixtures or in the same mixture with different heat treatment? What is it?

2. Is Al_2O_3 an essential ingredient of the batch in order to produce opacity from fluorine?

3. What is the gas evolved from fluorine glasses, i. e., does the fluorine come off as F or SiF_4, or both?

4. How does the fluoride affect the glaze or enamel as regards crazing and shivering?

5. In what form should the fluorine be added in order to obtain the greatest opacity with a given addition to the batch, i. e., is more F lost when it is added as cryolite than when it is added as sodium fluoride or fluorspar, or vice versa?

DISCUSSION

Mr. Landrum: Mr. Shaw's paper is really a discussion rather than a paper. It contains not only a splendid outline in research work in that line, but also a carefully compiled list of questions in regard to things that we enamelers—and I imagine glassmakers also—would like to know. A paper to cover this subject would be a lengthy one and would require a great deal of experimentation. Men engaged in college work could not find

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a better place for suggestions along this line than in this paper. I should like at some future time to write a paper on this subject and answer some of the questions that come from the work I have already done.

Prof. Silverman: I agree with Mr. Landrum that it is a subject for careful consideration. There are a number of points in it that I have already covered. Alumina is not necessary for the production of opacity in glass. Fluorine may or may not be present. The degree of opacity is dependent upon the combination of materials and types of material present. I am sorry that my researches are not complete and ready for publication, but I think that they will cover a great many points that were brought out in the form of questions in Mr. Shaw's paper—not only from the chemical aspect but historically as well.

Mr. Landrum: One point that might be of interest has, I suppose, been covered in the researches just mentioned. I have examined all these opaque enamels—containing tin or cryolite—and have found under a high power microscope that they contain a mass of very fine bubbles. The finer the bubbles the greater is the opacity. I have made no effort to explain this, but several answers suggest themselves.

Prof. Silverman: I do not want to prolong the discussion; but I believe in many cases clouding is due to the formation of blisters or bubbles. In other cases it is not due to this cause. There are some specimens that I have examined in which precipitation was responsible for the condition.

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INDUSTRIAL CO-OPERATION IN CERAMICS AT THE IOWA STATE COLLEGE

BY AMOS P. POTTS

At the State College, at Ames, Iowa, we have had, for the last five or six years, a ceramic course. I gave you a little talk about it last year, and mentioned that the students were a scarce article. Well, we have come to consider that a blessing, for last year the largest manufacturer of clay products in the state requested us to send one or more men to his factory, so as to go over the methods of manufacture in detail, and tell how to improve the quality of the product and cut down its cost. Not having any students, I went, and the experience has been of immense value to me, and of some value, I hope, to them. In fact, the rumors that have come to me have been quite complimentary.

Now this has opened up a new line of work, to my notion, and we have been seriously considering the proposition of making it a principal function of our department at Ames. To go out and educate the manufacturers and improve their methods of manufacture and improve their product, rather than sit in our offices and wait for them to send their friends or their sons to us to be educated. Five or ten years hence, this will produce the same results. Indeed, I think that they all admit that for quick results, the method of industrial co-operation is the method to use.

When you come to consider the cost, you may think that it is prohibitive; but we turned out a graduate last year who cost the state something like twenty-five hundred dollars for his senior year's education; and this year we are educating at least four superintendents, one general superintendent, and as many men as we can come in contact with through talks, or conversation, as we can get it, at considerably less expense to the state. The concerns that are having the work done are paying the cost of the work. The college or the state is paying the salary of the

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man on the job; so that, actually, it is not an expensive method of educating the clay workers of the State of Iowa—that is, from the standpoint of the state at large. The manufacturer gets what he pays for. The state is spreading the information that is desirable; so that, from that point of view, we consider that it is a successful move and an advisable one.

We have made many mistakes, but who does not, when starting out on a comparatively new line of attack. We hope, eventually, to get the matter standardized, so that we can do the work at considerably less cost to the state; by being able to take on more than four or five factories in a year, and by being able to cut down the time necessary for these investigations. At the same time, we will cut down the cost to the manufacturer to have the work done, by cutting down the time and, hence, cutting down the amount that he shall pay so that, in time,—and it will not take so many years, at the rate at which we have been going—our work will be of the same grade of efficiency that we are trying to instill into the manufacturer regarding his work, and its cost not at all prohibitive to him or to the state.

There are two complications that may arise—one, in particular. Suppose that some man trained in this work should enter the state and establish an office as a consulting engineer? We should then be competing with him on a basis that he could not meet at all. If that situation should arise, we shall have to adopt another method of handling the work. We might charge the manufacturer the man's salary, as well as his expenses, so as not to compete with an engineer who should come in to do business in a consulting capacity; but until that condition arises, we feel justified in going ahead as in the past.

Another condition that might arise is that if we get students, we shall have to stay and teach them, and not go out; but that difficulty can be met by employing enough assistants to carry on the work.

To give an idea of the work that we have done, I would say, in the first place, that we went at it in the wrong way. We undertook to go over the whole proposition at once, and then write up a report at the end of our investigation, telling what

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we had found, and making recommendations for improvement. From a scholastic standpoint, that is alright, but from a practical one, it is all wrong. When we have to do it over,—and, in fact, now.—we will go at one particular phase of the subject at a time. In taking a general survey, if the trouble seems to be with burning, we will take up the question of the burning, get that systematized correctly, and report on it; getting our report to the company quickly, so that they can fix this trouble and not get discouraged from waiting so long to carry it out. Whatever the trouble is, we shall attack one problem at a time and settle it, and then go on to the next one. That is the plan that we are to work on in the future; and if any of you have such a proposition come up, I advise you against trying to do the whole thing at once. It will prove discouraging. You get a great mass of data, and it is hopeless to try to write up a satisfactory report. The company gets tired waiting for it; and when it does come, it is more or less stale; because they may have talked the matter over; and by the time the report comes along, most of the errors have been corrected, and the report is not of very much value.

I have outlined the movement and explained, in a general way, the method of operation.

DISCUSSION

Prof. Orton: I want to ask a question. Do I understand that you now tax the firms for whom you work with a proportionate share of your expenses?

Mr. Potts: All my expenses are paid by them; and my salary is paid by the state, just as if I were teaching in the classroom. The firm pays my expenses when away from the college.

Prof. Orton: Then, in effect, the state is furnishing a high quality of expert service for the benefit of the individual manufacturer?

Mr. Potts: Yes; but we have the privilege of publishing all the results that we obtain. Any information that we obtain, we can publish for the benefit of the state.

Prof. Orton: I am greatly interested in this paper of Mr. Potts'. I saw him two or three weeks ago, and, in a hasty con-

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versation with him, I learned enough of the plan to know that it would be of interest here. I should think that the situation disclosed in Iowa would be difficult to adapt to states that are not so far West. These Western communities have a much more plastic frame of mind on all such questions as the relation of the university to manufacturers, and everything of that sort, than have those in the more Eastern states; and they are more willing to try experiments and adopt new notions. If we were to try in Ohio, for instance, the plan of sending instructors from the university to advise each plant as to its particular difficulty, and keep men there for any length of time, there would shortly, I fear, be a big outcry raised in the legislature against what they would call paternalism. I am not stating that I think it is improper for the state to do this, but merely that it would be difficult to get the public in the eastern part of the country, where the communities have become pretty settled and mature in their ways, to see that this should be done. It is easier to do it in the West, where they are younger and still willing to try any experiment in governmental method that comes along.

Mr. Joseph Keele: I just want to add a word of appreciation of the work that Mr. Potts has been doing in Iowa, and I think that in many instances it could be applied to the problems in Canada, where some kind of supervision seems warranted. Then, as to what Professor Orton has said about the conditions in the Eastern states, I think that we should have no such difficulty in the Eastern Provinces of Canada. They would be glad of any assistance that the Government ordered, Provincial or Federal, for the company. For instance, in the Province of Quebec, we wanted to emphasize the necessity for the production of drain tile. There is not one, at present, made in the province; and we shall sooner or later have to have some one, under either Federal or Provincial auspices to educate the people in making them, after they have been taught the necessity of using them. I am much interested in the work of Mr. Potts in Iowa, and glad that a movement in this direction has been made in other communities.

Mr. Potts: In discussing this proposition of state aid to

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manufacturers, I might bring up the fact that the people of Iowa and of other Western states with whom I have talked feel that the university belongs to them and ought to be doing something for them. Because they take this attitude, we are permitted to do this work. They are voting money and paying taxes, and they want some return. The Agricultural College has been doing such work for years, beside sending out trains and holding institutes all over the state.

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THE PRESENT STATUS OF THE PRODUCER GAS FIRED CONTINUOUS KILN IN AMERICA

BY R. H. M'ELROY AND G. R. MUMMA

Much interest is manifested throughout the country in the use of producer gas as a firing agent, in fact, several papers have been read before the Society on the subject. Some have been favorable to the American present day system, others have found much fault. All have been a compilation of data giving the writer's experience on one or two kilns, none have given the general status of the system throughout the continent.

Data taken from actual working conditions will rebut a few statements made before this Society.

We have no very definite records as to the advent of producer gas in the clay industry on this continent. Several experiments were made along the middle of the last century with both continuous and periodical kilns, but no great success was obtained. Soon after that, a decorating kiln was operated with more or less success, but not until the last quarter of the century was producer gas commercially and successfully adapted to the continuous system. The failures of the early experiments were due to a variety of causes, but were mainly due to neglect to take into account the fact that conditions of American manufacture are different from those of continental Europe.

The successful adoption of this type of kiln to American manufacture is due to the untiring efforts of the late P. L. Youngren. Thirty-six of these kilns are in actual operation, four of which are semi-continuous. Four more are building, three are idle, due to financial failure of companies operating them, and one has been dismantled after a good period of operation, so that about 90 percent of the kilns installed are now burning ware.

Two general types of kiln have been evolved; the tunnel as illustrated in Fig. 1, and the compartment as in Fig. 2. The tunnel variety is very similar in general construction to the coal-

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fired tunnel continuous kiln with the exception of changes in minor details. The producer gas fired tunnel kiln has been built enbloc with no central court, and carries the flues between the two tunnels. It differs from other tunnel kilns in having a watersmoking system as a part of its standard equipment. Why this has never been generally used in American coal fired kilns, we do not know. With most kilns of the tunnel type, the partitions between the sections are temporarily built of the green ware itself, flues in the ware being so arranged with the help of the drop arches, to cause up and down travel of the fire. The sections have so far been built in two general sizes—a 16 ft. wide, 10 ft. crown, 18 ft. length type, holding about 30,000 average sized brick to the section, and a larger, 20 ft. width, 11 ft. crown, 18 ft. length, holding about 40,000 to the section, experience having indicated that sections longer than 18 ft. can only be used at the expense of uniformity of burn. The tunnel type of kiln, so far, has been solely used in the burning of building brick and allied cheaper products; if anything, it burns a builder with several percent less coal than an equal capacity compartment kiln. Our only explanation of this phenomenon is that there are less walls to heat up in the tunnel type.

The burning capacity of the tunnel type depends to a great extent on the material to be burned on its finishing temperature, its ability in heating up and cooling, etc. To finish a section of the large 40,000 type in 24 hours of fire, about 18 to 20 sections are generally required for the average surface material, which material will finish in the neighborhood of 1800 to 1850°. Where a higher temperature is required, or a tenderer clay is used, 22 sections in such cases may be necessary. With an easy burning clay finishing near the above temperature, 16 sections are often sufficient, and by increasing on such material, the number of sections to 20 or 22, each section can be burned off in from 18 to 20 hours, giving a capacity of 50,000 and over per 24 hours.

Some idea as to the general construction of the tunnel type kiln can be obtained by an examination of Fig. 1.

Owing to the larger number of installations of the compartment type, the kiln has been mainly known through this type.

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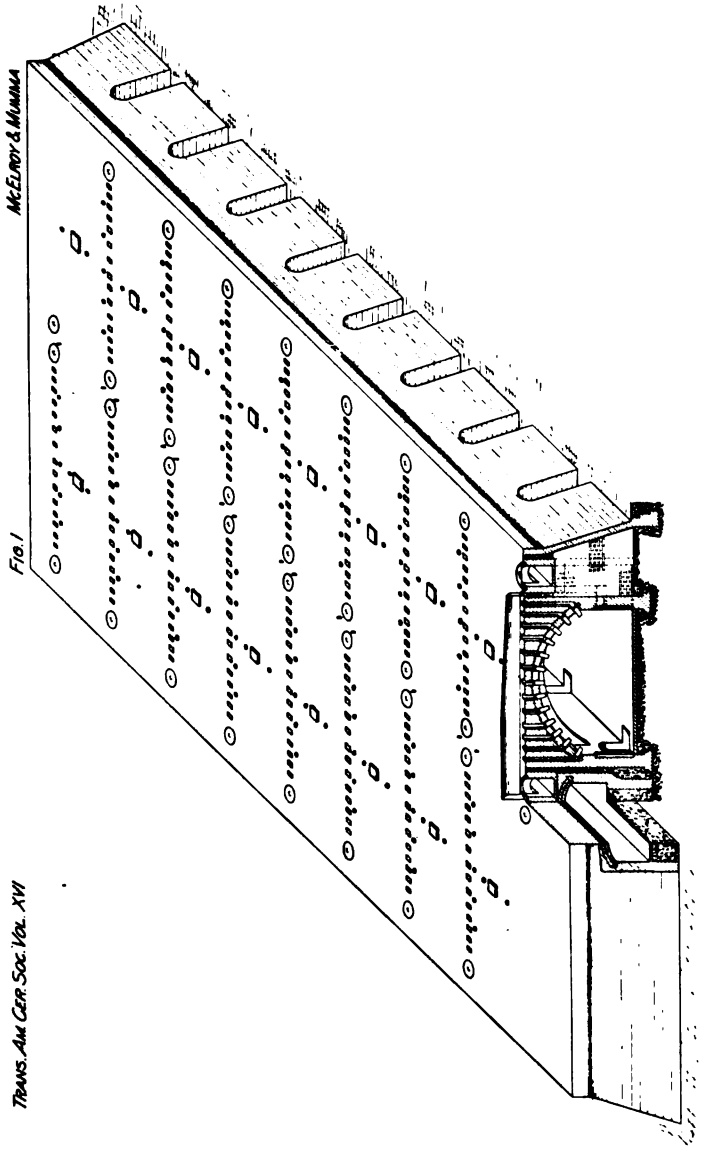

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Three general varieties have been evolved. The earliest was the back to back variety, resembling the tunnel kiln, being built en-bloc, that is, the draft flues being placed between the two rows of compartments. In this type, of course, the chambers could be entered only from one end. Then came the single battery type, placing the chambers in one straight row. Several semi-continuous kilns ranging from 8 to 10 chambers were installed in this manner. From this was evolved the double battery type with a court between, and nearly all of the late year installations have been so made. Figure 2 illustrates this. For the majority of new yards not cramped for room, this has proven to be the most effective. The chambers are all filled from the central court and emptied from the two extreme outsides, thereby removing any danger of conflict between the setting and emptying gangs. The enbloc or back to back type is a little cheaper to build on account of the less number of walls, and tends to save a little fuel over the other types, owing to its compactness. The single battery installation is very handy in operation, but we would not generally recommend it, except for those cases where the topography of the plant site and crowded conditions justify it.

Its one disadvantage, as compared with the other two, arises from the extreme length of the return heat flue, which in a 16 chamber variety returns the waste heat from No. 16 to No. 1.

The compartment kiln is used for the burning of practically all the commoner forms of clay ware, building brick, hollow-ware, face brick, flashed ware, paving block, drain tile, etc. It has a separate and distinct place as compared with the tunnel kiln, and should be and now is advocated for only the better forms of ware, also drain tile which does not readily lend itself to burning in the tunnel kilns.

As with the advent of all new departures in industrial lines, the evolution of the kiln has been necessarily slow. Mistakes have been made, disappointments have been met with, but slowly and surely, it has gained momentum from year to year. The early troubles were varied, many of which we will enumerate. There was lack of preliminary investigation of clays; a tendency

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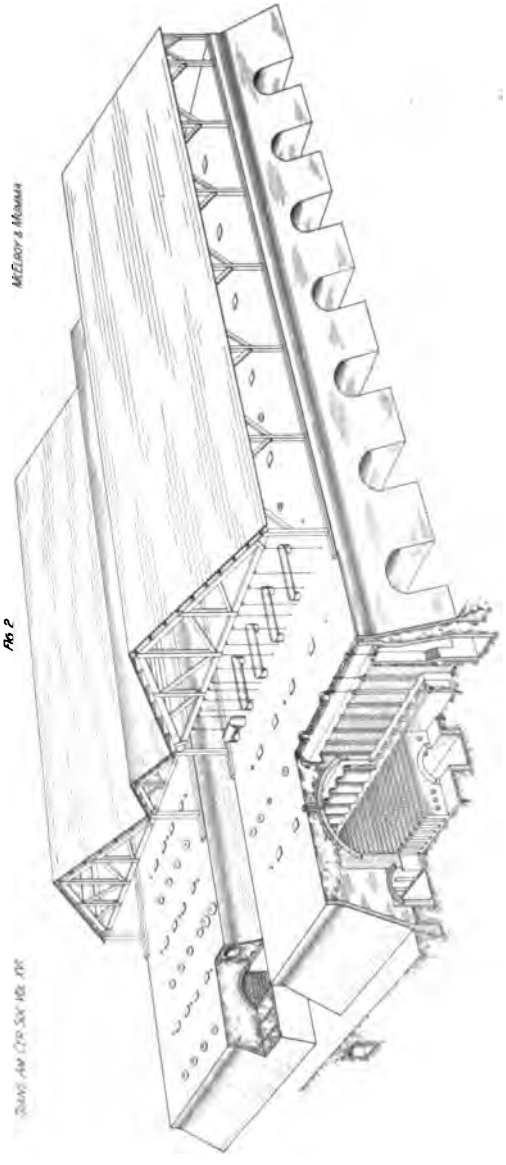

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to install a more or less general type for all cases; too small a number of chambers or sections; a tendency to construct the kiln of poor material; the use of producers that rapidly became inefficient and deteriorated quickly; the use of no controlling instruments; the inability to make the average brick maker who operated a kiln recognize that he had a high class instrument and that it must be treated as such. The main cause of trouble was the general lack of knowledge of how a kiln should be built and operated, as well as the inability to find experienced operators. Experience therefore gained through early mistakes has been the cause of putting the kiln on the plane now reached.

A couple of years ago, Richardson presented a paper before this Society detailing his experience in the operation of a semi-continuous compartment kiln. There is no better way in our opinion to show the wonderful improvement made in the last several years than to discuss the various difficulties he encountered.

The Producer. The first producer as used, in fact, the only one up to 1909, was of the rectangular suction type with mud seal. The walls were of brick and not steel jacketed. The constant expansion and contraction soon started many leaks in these walls unless they were taken care of properly. The air admitted burnt the gas in the producers causing them to run hot, cracking the gas as it emerged from the producers, causing much of the soot troubles he speaks of with this type. The only control over the flow of gas was the suction of a fan; the regulation of the flow of air and gas could not be separated. No apparatus was used as a guide to the performance of the producers.

For the last few years, a pressure producer of approved design according to Fig. 3, has been used instead in most cases. It is of the watersealed type, makes a richer gas, gives little chance of leakage, and allows the flow of the gas into the kiln under pressure. The old type of four-hopper producer, was practically four producers in one. In case a hole developed in the fuel bed in one end, it tended to burn the gas over the entire area, but with a water sealed, six-foot producer, a bad condition of fuel bed in one producer affects the gas from that producer alone.

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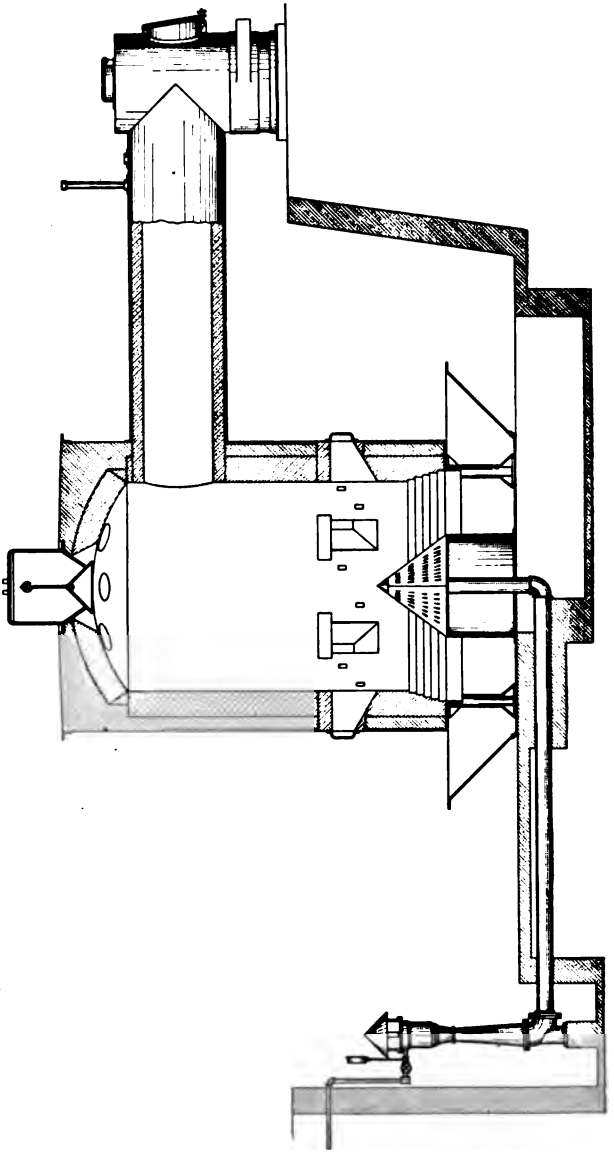

McElroy & Munna

Fig. 3

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The average of the gas, therefore, from all producers in such a case, is only that much below the average in quality as the one bad working producer affects it.

Experience has shown that the best temperature to take the gas from the producer is about 850°F. The necks of the new type of producer has been fitted with base couple pyrometers so that the temperature can be kept constant. Running at too low a temperature gives a surplus of tar; at too high a temperature tends to crack the gas, forming soot—besides burning the gas in the producer. Controlling the steam pressure accurately on the fuel bed and the temperature of the flowing gas eliminates a great part of the tar and soot, giving better results. It was necessary for Richardson to burn out about every round. With the new producers and pyrometers, the later kilns only have to be burnt out every several rounds. Again, a separate burn-out flue and stack have been added which facilitates the operation and cuts down the loss of sensible heat to a minimum. Fusible high ash coals are bound to give trouble even in the water sealed producer; and although the gas kiln can use fuels that a direct fired kiln cannot, we agree with Richardson in advising the use of the best coal that can be obtained. It gives less trouble in gasification, requires less producer area, and reduces the labor of firing.

Tendency of Gas Downtakes to Choke. The end downtakes in the old type were vertical, but many of the intervening downtakes were branching, several from one valve. All downtakes now are vertical, each being controlled by a separate valve, which gives a better control to the admission of gas along the bag wall and entirely eliminates the trouble as experienced by Richardson.

The Cracking of Gas Flues. The distributing flue as shown on Fig. 2, until recent years, was placed rather low between the crowns. The rise and fall of the crown, also the expansion and contraction of this flue tended to crack it, allowing the gas to escape through the kiln crowns. The flue is now being set higher; is self-contained on the dividing wall, and is built heavier.

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Tongue and groove brick further eliminate leaks, and as a false arch is now placed over the fire brick crown arch to take the weight of filling, most of this trouble is done away with.

The Number of Chambers. It is impossible to operate continuously on 8 to 10 chambers. Some clays can be handled fairly well with 12, but it is best to have more, in fact, the minimum number now being generally installed for the best burning clay is 16: Say, one chamber burning, five behind the fire, five ahead of the fire, one ahead watersmoking, two emptying, two filling and one extra to go on. In most cases 18 are now installed. The larger number of chambers, the less time the gas need be on each one, the point being to get as near as possible the finishing of one chamber every 24 hours. Quite a number of the later day kilns are now doing it regularly in from 28 to 30 hours, several in 24 hours, and a couple of tunnel kilns in 18 hours, some few in 48 hours.

Getting a Good Burn on the First Chamber. Trouble in this respect only occurs in the single battery type. Auxiliary furnaces have been installed at the extreme end in such cases. We know, however, of one 15 chamber single battery kiln which is operated in such an excellent manner that these furnaces are not used. The enbloc and double battery with court type is free from any annoyance of this kind.

The stack with the kiln is a thing of the past. The fan has superceded it entirely, giving more efficient service and greater uniformity from day to day. The steel vaned fan was entirely used up to several years ago. Since then copper vaned fans have been made a standard, as they hold out much better with high sulphur coal. Extreme cases of sulphur in the kiln gases have required either the installation of lead coated fans or the drawing off of the watersmoke and combustion gases through separate flues. Complete registering and recording pyrometers have been made an essential part of the equipment on all kilns, so that the control of the present day kiln is almost absolute. To illustrate

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this, Fig. 4 is here introduced. The record is dated November 20, 1913, and was taken from a Canadian kiln. This chamber was held for 24 hours through a shut-down in the manufacturing department, and the temperature was kept practically uniform for that period.

Last year before the Society, a paper on the producer gas fired continuous kiln was presented by Geijsbeek. He started his paper with the following statement: "It cannot be said in favor of the American producer gas fired continuous kilns that they have been a great success so far." This statement needs no discussion. The many users of the American producer gas fired continuous kiln are a rebuttal themselves. Two plants alone have installed three each, one kiln rapidly following the other, two have duplicated single installations, and one of the largest plants on the continent installed three at one time.

He further states "They (referring to the American system) are designed principally to use waste gases from the burning chambers to heat up the next chambers ahead of the fires and do not make any provision to regenerate or recuperate the air to be mixed with the producer gas." We emphatically disagree with him. What more ideal system could be obtained for the preheating of the air of combustion than to draw it through the cooling chambers. Heat the air to within a few hundred degrees of the temperature of the burning chamber and at the same time cool the chambers in uniform regularity.

Along a little further he says, "If there is a little draft in the first chamber behind the fire, there can be very little movement of the air and consequently only very little air can be available for the combustion of the gases in the burning chamber. We find, therefore, a lack of proper combustion." This is the first time that we have ever heard these charges made. Those who have had experience with the producer gas fired kiln have seen the flame leap from the bag walls and lick the crown with only 2 inches of draft at the fan. If there were not sufficient air for combustion, the condition of the burning chamber would be reducing instead of oxidizing. If such were the case, how do you account for the ability to put the gas in

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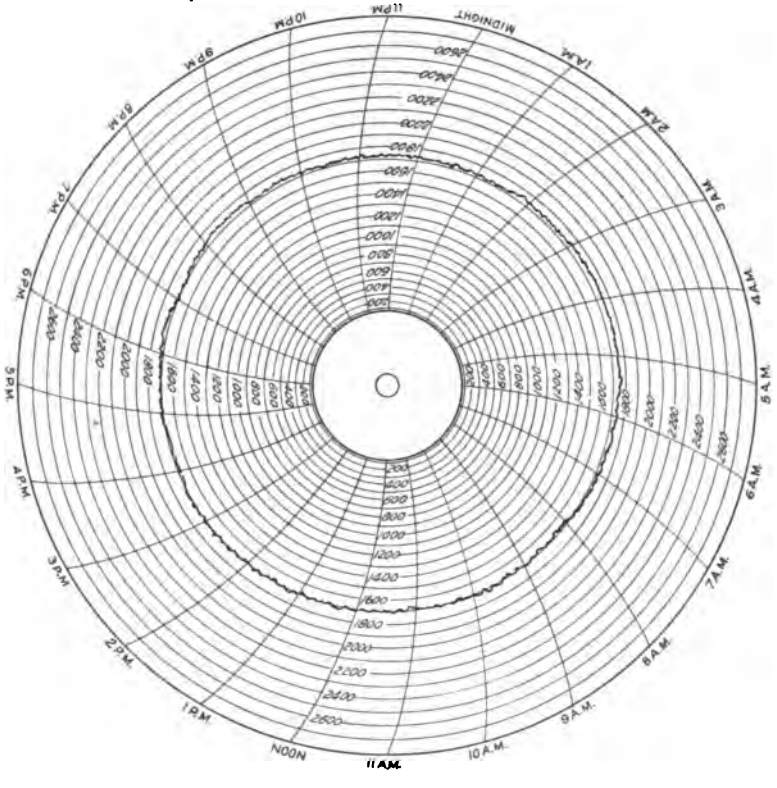
two consecutive chambers at the same time without the addition of any outside air whatever? Even then the chamber farthest from the air supply burns oxidizing. How could we raise the temperature of a burning chamber from 1350 to 1750°F. in 25 hours, as shown on Fig. 5, which record was taken December 1, 1913, if we had lack of air of combustion?

TRANS. AM. CER SOC. VOL. XVI FIG 4. McELROY & MUMMA



He further criticises the admission of the gas from the top (Fig. 2) instead of through the bottom flues, as is the German practice. The average chamber of the American kiln is from 15 to 60 ft. longer than those of European kilns. How will the underground distribution be made in long chambers? Can this

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method be adapted to American manufacture? Will it be successful? We, ourselves, are skeptical.

He further states, "The principle as practiced in this country to design and build a continuous kiln which will answer for all purposes and all kinds of clay products, for all local conditions and all different classes of fuel is not approved in foreign countries." Neither is it in this country. It is a fact that in the eary development of the kiln, this was too often practiced, but profiting by the experiences of our predecessors, we started the design of special chambers, sections, etc., for the burning of the different kinds of ware. To-day and for several years back, no kiln, to our knowledge, has been installed without an investigation of local conditions, the material, fuel, etc. Mistakes have been made, are now made and always will be made, but they are getting fewer each year. The material to be burned determines the width of the chamber, the height of crown, the length of the chamber and the number of chambers. The topography of the ground and local conditions determines the type of kiln, whether its flues should be overhead or underground. All of this, where possible is carefully looked into. The fuel is considered. Will it work in the regular producer? What grate area is required? How many producers will be needed? (One extra one always being provided.) The older kilns were installed with one fan. Now a reserve one is always provided, and in some cases three have been supplied.

Why is the producer gas fired continuous kiln desirable for the clayworker? The points to be discussed are: first, saving in fuel; second, saving in labor; third, facility of handling; fourth, uniformity of results; fifth, elasticity of operation.

Saving in Fuel. It has, indeed, been a hard proposition to educate the average clayworker to keep accurate tabulation on the quantity of fuel used in the kiln. The data that has been gathered shows a saving over periodical kilns of from 50 to 75 percent, the exact percentage depending on local conditions in manufacture, conditions of kilns where comparisons were made, etc. A compilation of results from four representative plants burning building brick in periodical kilns, temperature averag-

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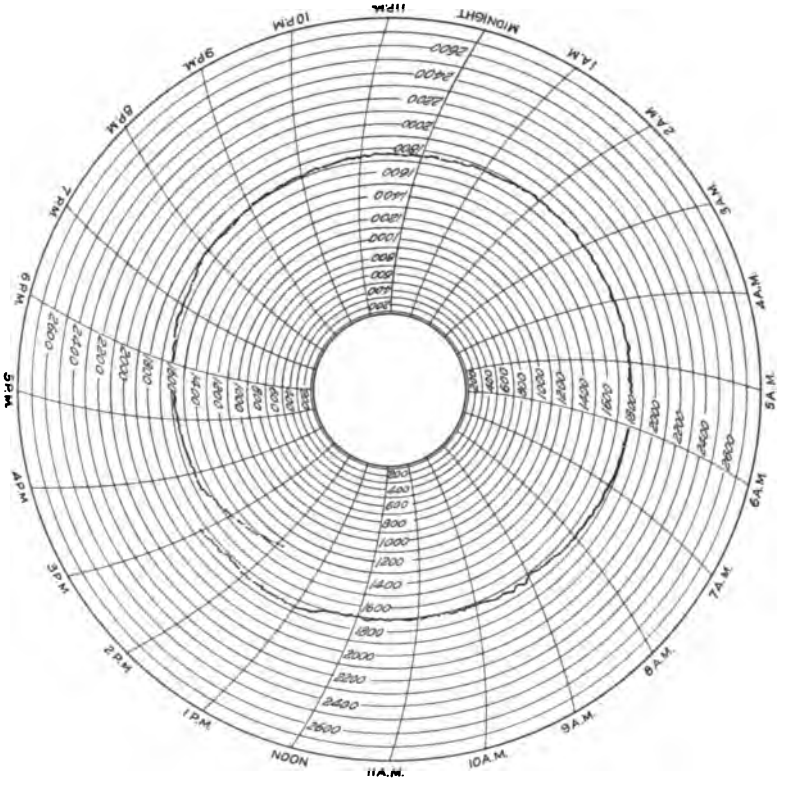
ing near 1850°F., average burnt weight 5.6 pounds, shows a fuel consumption of 950 pounds to the thousand brick. At the same time an average struck from the operation of three tunnel producer gas fired kilns burning for all practical purposes under

TRANS. AM. CER. SOC. VOL. XVI FIG. 5 McELROY & MUMMA



the same conditions, shows 298 pounds to the thousand, the saving of this particular compilation being 68.7 percent.

Richardson, in his paper, comparing a 10 chamber kiln burning face brick with down draft kilns on the same yard, gives 50 percent in his particular case.

Allow us to present here, data gathered from the operation of an 18 chamber kiln near Toronto, Canada.

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Material Used: Gray burning glacial drift—calcareous; red burning weathered top glacial and flood plain deposit—sandy.

Coal: Yohoghany three-quarter lump with slack and nut. Cost $4 per ton delivered.

Draft Gauge: Ohio make.

Pyrometers: Recording and registering. Temperature of gas in producer necks 850 to 900°F. Color of gas, bluish gray with yellow sheen.

Producers: Three in number; type, 6 ft. water sealed.

Product: Stock brick, green size 9 in. by 4 in., burnt size, 8¾ in. by 3⅞ in., burnt weight 5½ pounds. Chamber holding capacity, 58,000.

Steam Pressure: On the producer fuel bed, 60 pounds.

Draft: Chamber ahead of fire on admission of gas, .5 in., at finish, 0 in. Three chambers ahead of the fire on admission of gas, 2 in., at finish, 1½ in. Burning chamber at finish "minus" draft.

Vitrification Range: About 25°F.

Condition of Brick Burnt: All hard but not vitrified.

Fuel Consumption: 285 pounds per thousand brick.

Time of Burning: 25¾ hours. Chamber burned No. 6, containing red stock. Gas flues burnt out before starting fire on chamber.

Record of Burn: Shown on Fig. 6.

Date of burn, November 26, 1913.

Salable brick, 99 percent—face brick, 85 percent, building brick, 14 percent.

Saving in Labor. What constitutes the greatest labor in burning? It is the handling and movement of the fuel from place to place. The entire amount of fuel in the producer gas fired kiln is fed into the producers. These producers are segregated, therefore, the coal and ash are highly centralized, one bin above the producer sufficing for the coal supply. The coal can be dumped from the cars automatically and moved by suitable conveyors to the bins above the producers. From the bins, the fuel is readily fed into the hoppers, and it is only a question of time until the feeding of the hoppers will be automatic. Can

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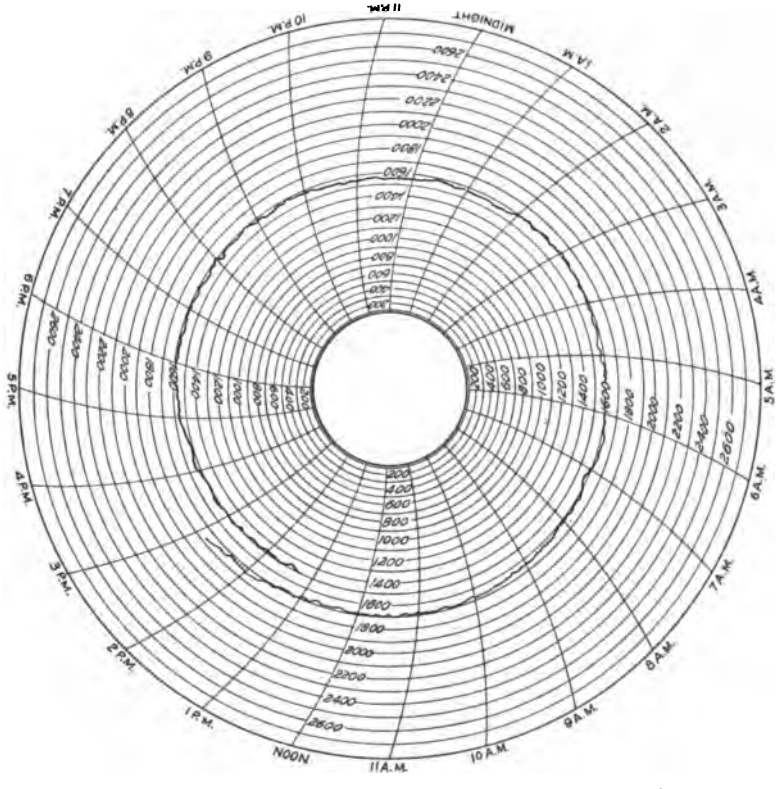
anyone imagine a more economical system of handling fuel? The ash, of course, is in small proportion to the fuel burned. It is damp and easily handled, a conveyor or elevator being most adaptable to its removal. Kilns, therefore, up to 70,000 to 80,000 capacity are being daily handled by two men on each shift. We might add here that the segregation of coal and ash

TRANS. AM. CER. SOC. VOL. XVI FIG. 6. McELROY & MUMMA



promotes cleanliness around a yard, comparing very favorably with natural gas firing in this one respect.

Facility of Handling. The industrial world is recognizing that greater facility and economy of operation is obtained through mechanical means. Wherever the human agency can be reduced to the minimum, the more uniform the results ob-

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tained. The producer gas fired continuous kiln as compared with other kilns is to a high degree mechanical. A certain amount of coal is fed into the producers at certain intervals. The pressure of the gas flowing into the kiln is a direct function of the steam pressure on the fuel bed and the speed of the fan. The amount of draft or the speed of the advance of the fire is controlled by mechanical means—a fan, and is, therefore, a matter of a certain number of revolutions per minute. Gas is admitted to the burning chamber by suitable valves operated from an advantageous position. The adaption to the kiln of recording permanent pyrometers in each chamber as well as producers, has furnished excellent control.

Uniformity of Results. The greater the percentage of A1 ware of whatever kind, the greater the profit on a given investment. A kiln that would burn all hard brick would be the ideal, but this is as yet an impossibility. If the average down-draft kiln produces 80 percent A1 paving block it is an exception and not the rule, in fact, we in no case have seen an ordinary down-draft kiln burn over 85 percent A1 paving block as an average the year around, but we do know of a producer gas fired kiln in Illinois that does average near 90 percent, and quite a number of chambers have been burned off averaging as high as 97 percent A1 block to the chamber. Now, this is a record that will, indeed, be very hard to equal. Further, a compartment kiln of the producer gas fired type near Knoxville, Tenn., burns chamber after chamber of red face and building brick practically all hard, in fact, averaging, they state, about 95 percent No. 1's the year around. Richardson in his article two years ago, after reciting his experience with a 10 chamber type kiln, states, "This type of kiln is the best that I have ever used for the burning of face brick (not flashed).

There is a plant in Ohio's Hocking Valley near the one Richardson referred to, where two producer gas fired continuous kilns are burning a brand of flashed face brick of the rough texture variety. All the brick are set on the flat for best flashing. We had cause several weeks ago to look over these kilns. We examined several different chambers, in one case took a brick

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from the next to the top course and one from the next to the bottom. The shrinkage was practically the same, the color of the bottom being only a shade lighter. The uniformity of burn now obtained there is indeed remarkable, as is the uniformity in color and the number of A1 brick. The results as obtained in the burning of face brick in this particular instance and in the instance mentioned by Richardson in his article, are without doubt the best that we have ever seen.

The producer gas fired continuous kiln is capable of such results in uniformity of action because first, gas and air are capable of most intimate association; second, the operation of the kiln is as near as possible mechanical; third, the continuous system is regular in procedure; fourth, the compartment kiln lends itself very readily to the best type of flue system. Let us not forget for one instant the use of watersmoking device, Figure 2.

The chambers or sections just set are watersmoked by means of pure hot air drawn from the cooling chambers. The combustion gases are not allowed to bathe the ware in those sections until the temperature has reached the point where danger of scumming from sulphur is eliminated. The uniformity of operation of the continuous system, its regularity in heating up and cooling, is well fitted for tender clay burning. An Arkansas manufacturer advised us several weeks ago that their saving in checking since the installation of a gas fired continuous kiln pays for the fuel used in the kiln. It must also be remembered that the ware taken from the chambers or sections of a gas fired kiln is always clean, and this cannot be said for the top coal fired continuous kiln and many types of periodical kilns.

Elasticity in Operation. The natural condition of continuous kiln burning is oxidizing. It tends to produce the normal ferric color in a clay. To our knowledge it is almost impossible in a coal fired continuous kiln to commercially reduce or flash the ware. In the gas fired kiln, the atmosphere can be almost instantly changed from highly oxidizing to highly reducing, this making possible the burning of high grade flashed products. Unless attention is paid to alternate reduction and oxidation in

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the burning of cream colored calcareous clays, they will show a pinkish tinge, the value of the gas fired kiln over the coal fired one, in this respect, being forcibly shown on one yard in Milwaukee, Wis., which possesses both a coal fired and a gas fired kiln. Besides it is practically impossible in the ordinary periodical kiln to burn under a purely oxidizing atmosphere at temperatures in excess of 2200°F. As yet we have not gone much higher than this temperature in the States, but we know that oxidizing conditions can be retained at much higher temperatures. In ordinary kilns, with clays, especially fire clays containing concretionary iron, or pyrites, the tendency is for the iron to black speck the ware through alternate reduction and oxidation. The regular oxidizing condition of a gas kiln eliminates this trouble.

There are many other points that we might take up, but these we will defer for some future paper. The gas fired kiln has come to stay. Every day it is becoming more and more foolproof. There are some conditions of manufacture that prohibit its use and always will, but we believe our experience has shown us that where its installation is feasible, it will burn better ware at less cost with less chance of trouble than any other type of kiln.

DISCUSSION

Mr. Richardson: In this paper we have no account of any new invention, but a discussion of statements made in two previous papers before the Society and brief data of results obtained in the burning of a single chamber of some kiln by someone in Canada.

Gas Producer. The gas producer now used by Raymond is undoubtedly superior to the old Youngren producer I described in my paper (Vol. XIV), but nothing new is claimed for it, and it is not the invention of the authors nor of their employers, nor have they any exclusive rights of manufacture or sale of such producer. There are several good producers on the market in this country, most of them what are known as "mechanical" producers, that is, such as have coal distribution and ash removing devices operated automatically by power. The selection of

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a gas producer for any specific purpose or conditions is not an easy problem, especially if the investment must be limited.

Gas Distributing Flues. If the partition walls between chambers are built heavy enough—4 or 5 feet thick—the gas distributing flue can, as the authors state, be self-contained and if built, as they say, of tongue and groove brick, with a false arch to take the weight of the filling probably such flue will not give trouble from leakage. But what about the long downtakes leading down from this flue through the partition walls? A good part of the trouble of leakage comes from the cracking of the walls of these downtakes. Also, what about the cost of building such distributing flues.

Number of Chambers. The authors state that 16 to 18 chambers are now installed. This may be practical with a clay maturing quickly at low temperature so that the ware can be burned with 24 hours' firing. The face brick that we are producing at Shawnee cannot be properly burned with 24 hours' firing. Therefore, we allow 48 hours for burning and hence can take two days for filling a chamber and two days for emptying, so that twelve chambers would answer very well, operated as follows: one filling, one emptying, four back of the fire, one under fire, three ahead of the fire heating up and two water-smoking. If I were to add one more chamber I would use five instead of four chambers between the one under fire and the one being emptied. I would not care to pull the combusted gases through five chambers ahead of the fire. The saving is not so much in this direction, and there is danger of discolored ware.

Burning First Chamber of Single Battery Kiln. The remarkable statement is made that "We know of one 15 chamber single battery kiln that is operated in such an excellent manner that starting furnaces are not used." Supposing that the chambers are 16 feet wide and the partition walls 3 feet thick, this means that the return flue would be about 300 feet long and that the hot gases from the burning chamber would have not only to heat up the brick in 3 to 5 chambers ahead of the fire, but would have to heat up a flue 300 feet long, and the combus-

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tion chamber of No. 1 at the end of this long flue would have to be heated to a low incandescence so as to ignite the gas and maintain combustion. I am not charging a misstatement of fact, but such a fact is so wonderful and unbelievable from theoretical considerations that it should be given the publicity of our Transactions. The authors should state where this is being done and under what peculiar conditions.

Hot Air for Combustion of Gas. The criticism of Geijsbeek's paper is probably due in part to a misunderstanding of his statements, but the authors are correct in stating that with proper draft control there is no lack of air for combustion and that the gas-fired kilns, like all continuous kilns, are regularly oxidizing, with an excess of air. This is especially true of the gas-fired kiln, since it is not necessary to fire more than one chamber at a time, if the kiln is properly managed, though at times two chambers are fired with complete combustion of the gas.

Admission of Gas from Top. Whether to admit gas to the kiln from the top or from the bottom is a moot question in kiln design. Much can be said on both sides. The advantages are decidedly in favor of admission of gas from the bottom unless the chambers are unreasonably long—more than 50 feet. To admit gas from the bottom in a very long chamber necessitates a sacrifice to some extent of the control of the gas at every point. Yet I believe this difficulty can be overcome in most cases. To properly discuss this point would require a separate paper, with drawings.

Designing Kiln to Meet Local Conditions. The authors fail to answer Mr. Geijsbeek's criticisms on this point. They may modify to some small degree the design of the kiln for special conditions, but it is well known that patent kiln promoters sell their particular type of kiln to everyone that they can persuade to adopt it and who are able to pay their charges. To be sure they make the statement in the concluding paragraph of their paper that "there are some conditions of manufacture that prohibit its use," but do not state what these conditions are.

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Their business is not in designing or recommending, as engineers would do, a kiln to meet the local conditions in any special case, but their efforts are all directed to the selling of a single type of kiln—the producer gas fired continuous kiln. They are hired for this, and their employer rates them by their ability to do this. I do not understand that Mr. Gejsbeek is criticising them in his general statement of the manner in which the kiln business has been mostly done in this country. The encouraging fact must be recognized that it is becoming to be considered a wise business policy to sell nothing to a man that is not well adapted to his needs, as satisfied customers are a most valuable asset. So that, as the authors state, there is undoubtedly a more careful investigation of conditions now than formerly.

There is one condition, however, that is apt to be overlooked, and that is the important one of whether the business to be done will justify so large an investment as is required for the producer gas-fired continuous kiln, and we frequently hear the complaint that the cost was misrepresented by the salesman, either intentionally or through the common mistake of underestimating.

If the authors want to do a real service to the members of our Society, let them, in the future paper that they promise, give detailed cost statements from the many manufacturers who have built these kilns, with an explanation of the conditions affecting the cost.

As to the advantages of the producer gas-fired kiln, most of them are applicable to any good continuous kiln and for low priced products to a greater degree with the coal-fired than with the producer gas-fired kiln. For the higher priced clay products especially for those requiring high temperatures, the gas fired kiln must take the lead. While the gas fired kiln can be manipulated, by controlling artificial draft, so as to give oxidizing or reducing conditions in the chamber being fired, one great advantage is that it can so easily be kept oxidizing, and flashing of the ware thereby prevented.

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SOME MISTAKES IN OUR TRANSACTIONS[1]

In Vol. XIV page 132, last paragraph, **including** should be **excluding** and should read: "By calculating the oxygen ratios of the glazes, **excluding** boric acids," etc.

The fourth paragraph should read:—"boric oxide as an acid, and as such whether free or combined its tendency is to **produce** crazing."

In Vol. XIV page 764, last part of the third paragraph should read: "Magnesia and magnesian minerals, when powdered, moistened with a solution of cobalt nitrate, and heated give a pink color. Alumina and alumina minerals when similarly treated give blue.."

In Vol. XV page 569, under Discussion, line 2, **glasses** should be **glazes**; line 5, **sand** should read **flint**; line 7 should read: "certain glazes both bright and mat much more **fusible** than the famous Albany slip,—

[1] Called to the attention of the editor by R. T. Stull, Urbana, Ill.

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